Developing Expert Performance in Sport:

Integrating Working Memory Training into Football Coaching

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This thesis is dedicated to the memory of

Theodore Smith Hall

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Toku toa, toku roha, toku mana, he toa rangatira

Kua hinga te tōtara haemata I te wao nui a Tāne

Haere rā Koroua

Abstract

Expert performance in football requires players to perceive, decide and execute actions in response to context, with reference to a playing model. The process to perceive, decide and execute actions can be referred to as perceptual-cognitive skill. Perceptual-cognitive skill is underpinned by the efficient use of the neural structures supporting working memory, associated with the correctly balanced application of declarative and procedural knowledge, also referred to as Flow.

Existing football coaching pedagogies can be used to develop domain-specific perceptual-cognitive skill, however, pedagogies that specifically develop the underlying neural structures supporting working memory function are limited. This research attempts to understand how the processes and structures underlying perceptual-cognitive skill can be developed, how working memory training (WMT) could be applied to football coaching practice and whether the use of WMT could develop skill performance in football.

The studies examined in this research allowed a conceptualisation of WMT applied within a football coaching framework using training principles of WMT prescription. This conceptualisation was investigated in practice in Study 1, using a participatory action research method. The data in Study 1 indicated an applicable transfer of lab-based WMT to practice, pedagogical guidelines for using WMT with athlete-centered methods of football coaching, and technological advances in administering WMT, including the use of remote response systems, bone conduction and sub-vocalisation technology.

Studies 2 and 3 investigated the impact of WMT on sub-elite and youth male football players performance in the Loughborough Soccer Passing Test (LSPT), compared to an Active and Passive Control. Study 2 found that WMT influenced overall performance in sub-elite male football players but yielded little benefit versus the Active Control. Study 2 also found little change in working memory performance, suggesting the LSPT may not replicate the real-world performance demands on working memory and/or that the prescription of WMT may not have been accurate. Study 3 combined the LSPT with the Stroop test to increase working memory demands, whilst also using an action-based metric to prescribe WMT. The results on youth football players showed that WMT may influence both skill accuracy and speed. Study 3 also found that working memory performance improved throughout the intervention, indicating that using the Stroop test and action-based metric improved the relevance of the LSPT to real-world performance and the accuracy of WMT prescription.

Future work should investigate these findings in more extensive studies, whilst collaborating further with coaches and athletes to develop pedagogies and technology that improve the application of WMT in football coaching. This research indicates that with refined methods of application, it may be possible for WMT to develop the structures supporting perceptual-cognitive skill, and therefore expert performance on domain-specific tasks in football.

Lay Summary

The aim of this research was to investigate how football coaching methods could be changed to target and improve structures of the brain that support the decision making and multitasking abilities required for skilled performance in football.

This research began with a review of existing work investigating the underlying processes and characteristics of skilled performers in sport, linking into work that describes the role of structures and processes that occur in the brain during skilled performance. Following the initial review, this research then reviewed studies that investigated training methods that specifically affect the structures and processes in the brain that support skilled performance. The outcome of the second review was the suggestion of a set of brain training principles for developing the parts of the brain linked to skilled performance in sport.

Following the reviews, this thesis integrated the suggested brain training principles into an existing football coaching methodology (the Game Training Model taught in Australia and New Zealand), which was then partly tested in Study 1 where the researcher worked with coaches and athletes in live training sessions to figure out how the new brain training methods might work in practice. This was repeated with adjustments made to the training each training session, based on feedback from coaches and athletes, as well as the observations of the researcher.

With an increased understanding of how the training might work in practice, it was then time to understand what impact brain training might have on skill. Studies 2 and 3 applied the new brain training methods on a test of football passing skill. Study 2 found some issues in how a football passing test replicated skill in a game situation, as well as some issues in how the new brain training methods were applied. Study 3 used an improved test that appeared to better replicate the decision-making processes involved in using football passing skill, whilst the new brain training methods were applied with a focus on the quality of the participant's actions. The results of study 3 suggested that the new training methods could influence both skill speed and accuracy, as well as influencing the underlying structures and processes in the brain.

In summary, this work was able to design new training methods that target the parts of the brain that support skilled performance, before testing how those methods would work in practice, and what the impact of those methods might be on performance. This research has created a road map for both methods and technology that will aid the use of brain training methods in football coaching, which needs to be investigated with larger numbers of participants with continued work alongside athletes and coaches.

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This thesis concludes six years of graft, satisfaction, frustration, becoming lost, finding the way, and ultimately, immense personal growth. Many have played their part in this journey and I wish to thank everyone who contributed to this work. I apologise in advance if I have lost you amongst the weeds as I try to piece together this experience and thank those who, accidentally or otherwise, spurred me on to completion.

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Here's to what comes next.

Contents

Publications and Presentations Arising from this Thesis

Hall, J. (2019). Developing expert performance in sport: Integrating Working Memory Training into Football Coaching. Presented at the World Congress on Science and Football, Melbourne, AUS

Hall, J. and Draper, N. (2018). Does a minimum dose of Working Memory Training during football skill performance impact results on a football skill test? Manuscript submitted for publication.

Hall, J. and Draper, N. (2018). Working Memory Training in a modified Loughborough Soccer Passing Test impacts skill performance in youth football players. Manuscript submitted for publication.

Hall, J. (2017). Integrating Working Memory Training into Football Coaching through action research. Presented at the World Congress on Science and Soccer, Rennes, FRA

Hall, J. (2015). Using Working Memory Training within a Games Sense paradigm in football. Presented at the Games Sense for Teaching and Coaching Conference, Christchurch, NZ

Hall, J. (2015). Development of Working Memory Training principles and integration into individual Football Coaching. Presented at the Annual Congress of the European College of Sports Science, Malmo, SWE

Hall, J. (2015). Bringing neuroscience into football training: principles of training working memory within Football Coaching. Presented at the World Congress on Science and Football, Copenhagen, DEN

Hall, J. (2014). Integration of Working Memory Training into contemporary best practice of Football Coaching. Presented at the International Symposium on Physical Education, Christchurch, NZ

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Abbreviations

WMT	Working Memory Training
BCT	Biased Competition Theory
DLPFC	Dorsolateral Prefrontal Cortex
RPE	Rate of Perceived Exertion
GPS	Global Positioning System
PAR	Participatory Action Research
CRS	Classroom Response System

Chapter 1: Introduction

1.1 Why investigate Working Memory Training and its relevance to sport?

The studies within this thesis are intended to advance coaching practice, therefore improving both athletes and football itself. Expert performance in football requires perception, decision making and skill execution in response to the objective conditions of the game, with reference to the processes of the team (Cross, Berger, Sherman, Verheijen and Williams, 2013; O'Connor, Larkin and Williams, 2018). This can be referred to as perceptual-cognitive expertise (Mann, Mark Williams, Ward and Janelle, 2007) or perceptual-cognitive skill (Caserta, 2007), with both terms used in Williams, Ford, Eccles and Ward (2011). Consequently, this thesis is concerned with the investigation of expertise within the context of perceptual-cognitive skill, which could better acknowledge the acquisition processes leading to "expertise", as well as the characteristics of expertise itself. Perceptual-cognitive skill and it's contributing characteristics are explored in detail during Chapter 2. The following text provides a brief synopsis of the contents of Chapter 2, giving context to this thesis.

Perceptual-cognitive skill is supported by the efficient use of working memory (Mann et al., 2007; Voss, Kramer, Chandramallika, Ruchika and Roberts, 2009; Pruna and Bahdur, 2016) and the neurological structures supporting the working memory system (Dietrich, 2004; Knudsen, 2007; Pruna and Bahdur, 2016), which provide a "hardware" for performance. The documentation of pedagogies that develop the "hardware" underlying perceptual-cognitive skill is limited in comparison to pedagogies that develop the processes of Perception, Decision Making and Execution (i.e. 'software"), which has been achieved through the replication of match demands in training exercises (Owen, Twist and Ford, 2004; Jones and Drust, 2007; Dellal, Chamari, Owen, Wong, Lago-Penas and Hill-Haas, 2011;

Cross et al., 2013; O'Connor and Larkin, 2017; O'Connor et al., 2018). The series of studies described in this thesis attempt to address this gap in knowledge by developing and investigating training methods that could develop the "hardware" underpinning perceptual-cognitive skill.

Research assessing perceptual-cognitive skill has been able to differentiate (Vestberg, Gustafson, Maurex, Ingvar and Petrovic, 2012) and/or identify (Ward and Williams, 2003), skilled athletes from unskilled athletes across a range of both individual and team sports. The perceptual-cognitive functions of experts can be traced back to the structure and function of working memory (Mann et al., 2007; Voss et al., 2009), a construct that explains how the temporary storage and manipulation of information (Baddeley, 2003) contributes to the execution of actions. Working Memory is a limited-capacity structure (varying by individual) that includes four interlinked components that store and manipulate information within a limited time-frame to guide action (Baddeley, 2003). The four components of working memory are (per Baddeley, 2003) the visuospatial sketchpad (which handles visuospatial information), the episodic buffer (which provides reference to long term memory), the phonological loop (which handles aural/verbal information) and the central executive (the controlling component of working memory). Due to its function, working memory is a structure that allows an individual to adapt and execute actions in response to context.

The execution of actions in this research is understood within the context of understanding explicit motor skills and implicit motor skills. Explicit motor skills are consciously controlled and are vulnerable under stress, fatigue and/or multitasking (Masters, Poolton, Maxwell and Raab, 2008; Verburgh, Scherder, van Lange and Oosterlaan, 2016; Buszard and Masters, 2017). Explicit motor skills are associated with declarative knowledge, described as a set of rules that are used to guide executive decisions (Maxwell, Masters and Eves, 2003; Furley and Memmert, 2010), and are supported by the cognitive system

(Dietrich, 2004; Knudsen, 2007). In contrast, implicit skills are skills that can be performed with little conscious control and are more stable under stress, fatigue and/or multitasking (Masters, 1992; Masters et al., 2008; Verburgh et al., 2016; Buszard and Masters, 2017). Implicit skills are associated with procedural knowledge, which is knowledge that we cannot necessarily describe or articulate (Maxwell et al., 2003; Furley and Memmert, 2010), supported primarily by the limbic system (Dietrich, 2004; Knudsen, 2007).

High perceptual-cognitive skill can be associated with an increased working memory capacity (Furley and Memmert, 2010) and/or more efficient use of working memory capacity (Schneiders, Opitz and Tang et al., 2012; Pruna and Bahder, 2016) – relating to the concept of an “economy of action” (Gabbett and Masters, 2011). The discussion of how capacity or efficiency are influential is complex, so literature addressing this issue is included during Chapter 2. In the context of motor learning, increased efficiency could be described as the result of how knowledge is weighted between implicit (procedural) or explicit (declarative) systems (Jackson and Farrow, 2005) – which influences the amount of conscious control during action, resulting in either an increased or decreased use of working memory capacity (Masters et al., 2008).

Within the literature, there is a difficulty in relating working memory to performance in sport, as it is unclear how motor input interacts with working memory (Buszard and Masters, 2017). As discussed in Buszard and Masters (2017), the existing working memory model does not have a component that specifically accounts for motor input, highlighting that the current literature explains the relationship between working memory and motor learning (see Maxwell et al., 2003) but not the mechanism of motor input. For example, Buszard and Masters (2017) theorise that the spatial component of working memory holds motor error information, which assists in motor adaptation, but it is not clearly defined which part of working memory interacts with which part of motor function. Consequently, the relationship between motor input and working memory is difficult to understand fully. For now, Buszard and Masters (2017) suggest that it would be helpful to focus on research related to executive function, as regardless of the mechanism(s) involved, it is apparent that efficient use of a limited working memory capacity (mediated by the central executive) can be associated with perceptual-cognitive skill, and consequently, the successful execution of actions relevant to performance.

In relation to the efficient use of working memory and the mention of an “economy of action” and an “economy of attention” by Gabbett and Masters (2011), Flow state, in brief, is a state of optimal arousal supporting skilled performance, involving, amongst other effects, a perceived sense of automacity and an absence of any fear of failure (Csikzentmihalyi, 1996). According to Dietrich (2004), Flow state is associated with a state of hypofrontality, where activation in the cognitive system (specifically in the frontal cortex) decreases in favor of activation in the limbic system. Therefore, Flow state can be associated with decreased use of working memory, which relies on structures in the cognitive system, suggesting that there is increased use of procedural or implicit knowledge during Flow.

An alternative to Flow state - “Choking” - involves a breakdown in skilled performance (Schmader and Johns, 2003) that can be related to the overload of working memory capacity through distraction (Beilock, 2008), over-arousal (Furley and Memmert, 2010) and/or explicit monitoring of implicit actions (Baumeister, 1984; Yu, 2015), also described as reinvestment in Masters (1992) and Masters and Maxwell (2008). These factors are not mutually exclusive, meaning that Choking can be caused by a combination of distraction, explicit monitoring (reinvestment) and over-arousal (Yu, 2015). Therefore, Choking can be associated with the inefficient use of working memory, an inverse of an “economy of action” (per Gabbett and Masters, 2011).

With Flow associated with skilled performance and Choking associated with a breakdown in skilled performance, environmental factors that contribute to Flow and interventions that limit Choking have been well researched (Yu, 2015), including expressive writing (Ramirez and Beilock, 2011) and reframing (Autin and Croizet, 2012). Environmental approaches influencing Flow include implicit motor learning strategies such as analogy learning (Liao and Masters, 2001; Poolton, Masters and Maxwell, 2006; Lam, Maxwell and Masters, 2009) or constraint-based exercises which provide an external locus of control during action (Furley and Wood, 2016; O'Connor and Larkin, 2017; O'Connor et al., 2018). In addition, performance environments are suggested to be built with favorable conditions for Systemic Creativity and Flow in mind (Csikzentmihalyi, 1996), which can be done using coaching pedagogies facilitating elements of self-organisation, intrinsic motivation and problem-solving approaches (Bakker, Allen and Hitch, 2011; O'Connor and Larkin, 2017).

With the knowledge that the brain contains plastic structures (Pascual-Leone, Amedi, Fregni and Merabet, 2005), this research considered the idea that there could be a method of using the plasticity of the underlying structures of working memory, such as the dorsolateral prefrontal cortex (DLPFC - Dietrich, 2004; Knudsen, 2007; Pruna and Bahder, 2016), to improve working memory. Theoretically, based on the link between working memory and performance, developing the use and/or function of working memory could positively affect perceptual-cognitive skill.

Working Memory Training (WMT) is a method that can develop the plasticity of structures underlying working memory (Dahlin, Nyberg, Bäckman and Neely, 2008; Loosli, Buschkuehl, Perrig and Jaeggi, 2011), providing a way to systematically overload working memory (Atkins, 2011), with evidence of performance changes in trained and transfer tasks (Chein and Morrison, 2010; Bastian, Langer, Jäncke and Oberauer, 2013) throughout different age groups (Smith, Housen and Yaffe et al., 2009; Brehmer, Rieckmann and Bellander et al., 2011). WMT involves the specific dosing of tasks with increasingly difficult demands on the storage and manipulation capability of working memory. Tasks such as the Digit Span backward (Brehmer et al., 2011), where the participant has to repeat a sequence of items in reverse order, or the N-back task (Heinzel, Schulte and Onken et al., 2013), where the participant has to match items in a sequence that are N places apart, provide a way to overload working memory. In addition, a number of studies have used novel storage and manipulation tasks to train working memory (Loosli et al., 2011; Smith et al., 2009) with evidence of trained and transfer gains.

As detailed in Chapter 2, the prescription of WMT involves the correct management of volume (time completing WMT), task difficulty (individualised based on the participant using an algorithm), frequency (the frequency of training sessions) and, with reference to football, domain-specificity to address the retrieval of implicit motor input required for executing a football action. Therefore, a challenge was not only to assess whether WMT could influence skilled performance, but to also integrate WMT into Football Coaching practice, enabling training with domain-specificity. Chapter 3 begins to address this challenge by presenting a conceptualisation of a Football Coaching methodology that includes WMT.

Football Coaching is discussed in this research in the context of the Game Training Model used by the Football Federation of Australia (Cross et al., 2013; O'Connor et al., 2017) and the Oceania Football Confederation as a frame of reference for the structured delivery of Football Coaching. The Game Training Model bases all components of its process on the context of the team and its objective, using a combination of task-based, constraint-based and situated learning. In addition, the physiological aspect of coaching practice is considered, as the Game Training Model needs to be applied in a manner that helps players remain injury free, whilst building tolerance to the load required by training and competing

(Iaia and Hawkins, 2017). This is achieved through load monitoring and prescription and the appropriate periodisation of all exercises (Iaia and Hawkins, 2017).

To integrate WMT into the Game Training Model, the principles of each need to be understood. WMT, with its principles of volume, difficulty, frequency and domain-specificity (described in Chapter 2), and the Game Training Model, with its hierarchical and episodic organization of a team Playing Model into processes and tasks. The combination of this knowledge allows the conceptualisation of how WMT can be implemented within coaching practice, which is explored in Chapter 3.

With domain-specificity in mind, a point highlighted by Buszard and Masters (2017) is the need for a more dynamic approach to research methods investigating the relationship between working memory and skilled performance in sport. Current lab-based measurements do not appear to accurately translate into practice and may not be enough to increase the understanding in the field, leading to the suggestion that the investigation of working memory and sport should use more dynamic skills. This issue of accuracy is reflected in Serpiello, Cox, Oppici, Hopkins and Varley (2017) who found that results on the Loughborough Soccer Passing Test (LSPT), a football skill assessment protocol, translated poorly to in-match metrics of skill performance. As it is currently difficult to simulate the practical setting that needs to be investigated, it is also difficult to test the effects of training methods such as WMT in a “real-world” setting. In addition, the repeated application of training methods within the lab means that there may be a negligence of exploring what would be required to take these methods out of the lab and onto the pitch. As Farrow, Reid, Buszard and Kovalchik (2017) comment, applied research engaging stakeholders could be a solution to the issues presented by lab-based training. Therefore, the next step in integrating WMT into Football Coaching lay in how WMT could be combined with coaching behaviors during a training session. This issue is addressed within Chapters 4 and 5 of this thesis using a

Participatory Action Research (PAR) methodology detailed and then applied to investigate the in-session application of WMT. PAR involves the collaboration of athlete, coach, and researcher to collect and analyse triangulated data in a practical setting. The ability to deliver WMT within football training also satisfies the need for domain-specificity (Takeuchi, Taki, Sassa, Hashizume and Sekiguchi , 2013) when attempting to use WMT effectively and efficiently.

Regardless of the ability to integrate WMT into coaching practice and behaviors, it remains to be seen what the impact of WMT on skill performance could be once the methods of application are understood. Therefore, Chapters 6 and 7 contain two quantitative studies investigating the impact of WMT on performance in a football skill test, the LSPT (Ali, 2011). The study in Chapter 7 provides an advancement on the existing LSPT procedure by introducing the Stroop test (Kane and Engle, 2003) to increase selective and controlled attention demands, closer to simulating the processes required to perform skills in match-play.

To conclude, the literature highlights that there are gaps in knowledge as to how the structures supporting working memory and perceptual cognitive skill function and/or could be developed for use with coaches and athletes. There is also a gap in understanding how these issues can be investigated in a practical setting, and finally, how the use of WMT could affect skill performance in football. Following the sequence of research detailed in Chapters 2 through 7, Chapter 8 provides a discussion addressing key knowledge gaps and findings, providing guidance on practical implications and future work. The following section provides a summary of the research aims and subsequent process that took place.

1.2 Research aim

The research aim was to investigate whether specific training that targets the underlying systems of Perception, Decision Making and Execution (i.e. working memory) could be integrated into Football Coaching. This led to the research question:

- What form of training would be suitable for developing the structures supporting Perception, Decision Making and Execution in football?

Firstly, a literature review on expertise in sport was conducted, which also investigated the link between working memory and expert performance. This was followed by examining WMT, ending with a summary containing suggested principles (volume, frequency, complexity, specificity) of prescribing WMT.

The literature review raised the possibility that WMT use could be beneficial to developing the process of Perception, Decision Making and Execution. The findings from the literature review needed to be contextualized to Football Coaching, leading to two further questions that guided the next part of this research:

- How could WMT be systemised and conducted in the context of Football Coaching?
- How does WMT influence football skill performance?

The two questions above were addressed in two stages:

- Question 1 is addressed by Chapters 3, 4 and 5. Chapter 3 contains a theoretical application of WMT to in-session Football Coaching methodology, specifically the Game Training Model (Cross et al., 2013). Chapter 4 presents the PAR methodology used to investigate the application of WMT within Football Coaching sessions. Finally, Chapter 5 contains the findings and analysis of Study 1, a PAR study with implications for the in-session development and use of WMT.

- Question 2 is addressed by Studies 2 and 3 (presented in Chapters 6 and 7); two quantitative investigations into the effect of using WMT on the performance of football skill, using the LSPT with an integrated WMT intervention. Study 2 provides an initial investigation, whilst Study 3 extrapolates the method of Study 2 to a larger sample with a refined testing and intervention methodology.

The implications of the research are discussed in Chapter 8, providing a future direction for the investigation of using WMT in Football Coaching. The thesis is then closed, followed by the appendices.

1.2.1 Delimitations

The studies detailed in this thesis include both qualitative and quantitative research methodologies. Delimitations common to Studies 1, 2 and 3 (reported in Chapters 5-7 respectively) were:

- The principles and application of WMT in this research were based on the studies examined in Chapter 2.
- Football Coaching is understood in the context of the Game Training Model (Cross et al., 2013).
- Participants in the studies were amateur athletes with other responsibilities, so where possible, the studies were conducted as an addition around their normal football commitments to encourage an acceptable attendance level for the research.

Both neuropsychology and sports coaching are broad fields, and therefore these three delimitations allowed the investigation of WMT and Football Coaching to be conducted within specific parameters, making the investigation more controllable under the assumption that these delimitations represent a form of current/best practice from each field, within the constraints of available participants.

1.2.2 Assumptions

An objective of this research was to determine what form of training would be suitable for developing the structures supporting Perception, Decision Making and Execution in football, leading to the investigation of WMT. However, no existing methods for using WMT in Football Coaching were present in the literature. Consequently, the research investigated how WMT could be integrated into Football Coaching (Study 1), to then begin investigating the impact of WMT on skilled performance (Studies 2 and 3). This followed the assumption that it could be possible to transfer the lab results of WMT in neuropsychological research into a new context – Football Coaching, based on the WMT literature indicating the possibility of trained and/or transfer effects from WMT dosage.

Further assumptions, ordered by Study, are detailed below:

Study 1

- It is assumed that during the process of collecting the qualitative data, both coach and athletes approached the training, conversations and interviews in both a diligent and honest manner.

Studies 2 and 3

- There was an assumption that participants gave maximum effort within the rules of the LSPT protocol for the full duration of Studies 2 and 3.

1.2.3 Limitations

A limitation of this research is the performance level of participants, ranging from sub-elite (regional top league) to competitive (regional youth league), therefore one of the assumptions of this research is that the methods and results presented here are in some way transferrable to other demographics.

A second limitation of this research is the inability to test the use of WMT in match situations, due to the inherent variability and novelty of skill performance in football. Study 1 addresses ways in which WMT could be incorporated into training, but it remained too complex for the scope of this study to accurately test in-match performance as the intervention(s) used wouldn't be replicable due to contextual factors, such as opposition styles of play.

The limitations of each study, ordered by Chapter, are detailed below:

Study 1

- The use of sub-elite athletes created a limitation whereby the availability of athletes was limited following the end of PAR cycle 3 due to the end of the academic year, leading to a lack of interview data following cycle 3. The gap between action and interview could have led to a less accurate recollection of events by participants, compared to the interviews in previous cycles that occurred within 24 hours of the training sessions. This was mitigated by triangulating Cycle 3 with data from video analysis, researcher-coach dialogue and researcher notes.
- A limitation of qualitative research, in general, is that it is difficult to generalise the findings to a wider population. This applies to PAR due to the focus on rich data collection from a small number of individuals who are assumed to have in interest in the research itself.

Studies 2 and 3

- The inability to test more than a minimum dose due to athlete availability, dictated by not having access to full time athletes over the course of full or multiple seasons. However, given the novel nature of using WMT within the LSPT, using a minimum dose over a limited period carried the advantage that any methodological issues would not have derailed a large scale and/or long-term data collection protocol and wasted valuable resources. In fact, the application of a minimum dose has allowed methodological outcomes to be drawn from Studies 2 and 3, contributing valuable methodological guidelines to future research using larger samples, over longer periods of time, with a higher dose intervention.
- There was a lack of available participants and equipment required to scale the quantitative studies in Studies 2 and 3 to a larger proportion of the playing population.
- There was inadequate time to scale the research by organising equipment for different regions and to either (1) travel to different regions to collect data, or (2) educate researchers in how to conduct the data collection in their own environment
- There was inadequate funding available to cover the financial cost of conducting research across multiple regions, which have been a limitation even if there was adequate time to attempt to scale the studies to a larger sample size.
- Unique to Study 2, one limitation regarded the LSPT itself, where the ambiguity surrounding the validity of the LSPT scores compared to in-match performance (Serpiello et al., 2017), believed to be due to an inaccurate simulation of the performance demand on working memory, meant that the generalisation of the results to the practical context of playing football was limited. This limitation was addressed in Study 3 through the incorporation of the Stroop test into the performance of the

LSPT, simulating the selective/controlled attentional demands of skill performance in football.

1.3 Thesis structure

This thesis is structured to demonstrate the journey of this research in chronological order, via a series of studies. This is designed to ensure that each Chapter has a clear point of reference for its rationale, based on the previous Chapter. Each Chapter ends by summarizing its conclusions and using them to provide a rationale for the following Chapter, which begins by linking to the previous Chapter and explaining how the following text is structured to present the next step in the research journey. The purpose of structuring the thesis this way is to pay homage to the applied and emergent nature of the research, evolving constantly throughout the investigative process.

The literature review in Chapter 2 is split into two main sections. The first section (2.1) is a review that seeks to understand the basis of expertise in sport and the relationship between expertise and working memory, providing the foundation and rationale to investigate methods of developing working memory. The second part of the literature review, section 2.2, is a systematic literature review of WMT. Section 2.2 investigates how WMT has been previously used and what effects have been recorded to create a set of training principles that represent the most effective method of applying WMT. These are studies of a lab-based nature, providing a rationale for the contents of the next stage of the research, investigating the application of WMT within the applied domain of Football Coaching.

Chapter 3 begins with a reflection on the position of WMT in relation to coaching, then describes the theoretical application of WMT to the context of coaching pedagogy in two sections, the first (3.1), discusses the Game Training Model (Cross et al. 2013) and second (3.2), explores how WMT may be used within a single training session. Chapter 3 continues with a philosophical section describing the theoretical framework that is used to understand the qualitative data presented in Study 1, Csikzentmihalyi's Flow and the systemic view of creativity in action. The framework provides a hierarchy to understand how Flow actions occur (or don't occur) which allows the qualitative data to be analysed in a systematic manner.

The purpose of Chapter 4 is to detail the qualitative research methodology used in Study 1 to investigate the use of WMT within Football Coaching sessions. Section 4.1 provides a case for the use of a PAR method, section 4.2 provides background on PAR methodology and the previous use of action research in sports coaching research. Section 4.3 describes the PAR research design used to investigate the application of WMT within Football Coaching sessions, describing each step of the PAR process. Sections 4.4 and 4.5 detail ethics, limitations and assumptions of the research respectively, with 4.6 introducing Study 1 (Chapter 5) by providing a detailed explanation of how the analysis is presented and should be read.

Chapter 5 details Study 1, section 5.1 presents the data analysis from the first Cycle of PAR, whilst sections 5.2 and 5.3 contains the analysis of data from Cycles 2 and 3 respectively. Chapter 5 concludes by categorising and summarising the outcomes of the research process and outlining the implications for future research.

Chapter 6 presents Study 2, which investigated the impact of using WMT on skill learning and performance during the LSPT. The Chapter concludes by discussing the possible shortcomings of existing skill testing in football and lays the foundation for Study 3, presented in Chapter 7, which introduced action-based performance measures to adjust WMT task difficulty and the Stroop task to introduce controlled and selective attention to the LSPT, used on an increased sample from Study 2.

Chapter 8 contains the discussion, beginning by collating and presenting the findings of each study in section 8.1. Discussion of the research findings takes place in sections 8.2-8.4, addressing the relationship between the research and existing literature, gaps in knowledge addressed by this research and the limitations of the research in relation to the literature. Chapter 8 concludes with section 8.4, discussing the future work arising from the research findings. The thesis is then closed in 8.5 with references and appendices to follow. Table 1.1 on the following page presents the research process:

Table 1.1 The Research Process

	Research Question	Chapter	Format
Theorising	What form of training would be suitable for developing the structures supporting Perception, Decision Making and Execution in football?	2 (2.1)	Literature Review: Working Memory and Sports Performance
		2 (2.2)	Systematic Literature Review: WMT
	How could WMT be systemised and conducted in the context of Football Coaching?	3	Theorising and Model Creation: WMT in Football Coaching methodology (Game Training Model)
		5	Study 1: Applying WMT in Football Coaching using PAR
Investigation	How does WMT impact skill performance in football?	6	Study 2: Does a minimum dose of WMT during football skill performance impact results on a football skill test?
		7	Study 3: WMT used with a combination of the LSPT and Stroop Task influences skill performance in youth football players

1.4 Chapter 1 Summary

This introduction has provided a context to the studies in this research by exploring the literature, research aim and a road map of how the thesis will progress. The following Chapter contains two literature reviews, the first exploring expert performance and the link to working memory and sport, the second investigating the use of WMT. The purpose of Chapter 2 is to inform the theoretical and methodological approaches detailed in Chapters 3 and 4 respectively, whilst providing a foundation of knowledge for the subsequent studies (Chapters 5 through 7) which contain the studies that form the basis for discussion and the conclusion of the thesis (Chapter 8).

Chapter 2: Literature Review

2.1 Understanding expertise: The link between working memory and sports performance

This Chapter contains literature review covering the fields of attention, perceptual-cognitive skill, decision making and perception in relation to working memory and its application to sport. The execution of these processes has been shown to identify (Ward and Williams, 2003), differentiate (Vestberg et al., 2012) and define (Voss et al., 2009) skilled performers in sport relative to lesser-skilled performers. The relevance of these fields to practice will be covered, with the focus on the underlying functions and neural correlates to help understand how expert performers operate. This knowledge will help inform the conceptualisation of training methodology in Chapter 3. This Chapter is organized into several sections that include working memory, motor integration, Flow theory, Choking theory, perceptual-cognitive training and the associated neural correlates of each concept. The Chapter is ordered with the intention of leading from the underlying processes of action to performance and training implications.

2.1.1 Introduction

To understand the content of the field clearly, some language needs to be clarified and understood. The terms “attention” (Knudsen, 2007; Gray and Bjorklund, 2014), “perceptual-cognitive skill” (Caserta, 2007), “decision making” (Voss et al., 2009) and “perception” (Williams, 2000) can appear to be overlapping terms in the literature, and due to the wide psychological application and use of each term, it is important to contextualize the meaning of each term relative to this Chapter. “Attention” refers to how we actively select a subset of information from the information available to us (Duncan, 1999). Due to the limited amount of mental resources that we have at any given moment, it is important that we process only relevant information while ignoring or inhibiting irrelevant information. Attention can be goal-driven or stimulus-driven (Egeth and Yantis, 1997). It is goal-driven when it is subject to the control of an observer (e.g., when one is looking for his car using his knowledge of its color and shape). It is stimulus-driven when it is controlled by some salient feature not necessarily relevant to an observer’s behavioral goal (e.g., when a yellow car stands out among an array of black and gray cars). Attention can be distributed widely over a large area or focused narrowly at a small spot (Eriksen and St. James, 1986). Attention can also be shifted between different locations or objects, but the shift of attention typically comes with a resource cost (Chen, 2012).

“Perception” is a process where an individual selects and processes information. Williams (2000) further distinguished this for sport by using the term ‘skilled perception”, referring to the degree in which an individual selects information for processing and the accuracy of the decision-making response. The term “perception” has also been mentioned as a separate process to attention (Voss et al., 2009), whilst ’skilled perception” is mentioned as part of decision making (Williams, 2000), which as noted above, has been intertwined with attention (Mann et al., 2007). This is an example of how terms can appear to overlap in the literature, despite their differences, as perception refers to both the selection and processing of information, whilst attention refers to only selection.

“Perceptual-cognitive skill” (Caserta, 2007) is referred to as the ability to identify and acquire environmental information to integrate with existing knowledge to inform and select an appropriate response (Marteniuk, 1976, as cited by Mann et al., 2007). The integration of stimuli with existing knowledge is handled by working memory, whilst the subsequent selection of appropriate responses in working memory can be explained as “decision making”- a concept mentioned in sport through the use of phrases such as “tactical awareness” (Faubert and Sidebottom, 2012).

All these terms are relevant to the processes that occur during sport, however, the overlapping nature of each term throughout the literature can make it hard to understand where each term is relevant. Considering this, this Chapter focuses on the functional and neural processes that underlie cognition in sport, and the focus will be on the processes themselves. The overall subject matter will be referred to as perceptual-cognitive skill, as this term appears to account for both the acquisition and function of expertise with relevance to the performance of actions in football - Perception, Decision Making and Execution (Cross et al., 2013; O'Connor et al., 2018).

Perceptual-cognitive skill is underpinned by the function and use of working memory (Mann et al., 2007; Voss et al., 2009) which, from a neurological perspective, is supported by activity in many areas of the brain, including the prefrontal lobe and the parietal lobe (Dietrich, 2004; see Baddeley, 2007, for a review on working memory). Working memory is concerned with the temporary storage and manipulation of information (Baddeley, 2003), as well as generating signals that improve the quality of information processed (Miller and Cohen, 2001; Miller and D'Exposito; 2005) for the guidance of behavior and decision making (Williams, 2000; Ward, 2003; Mann et al., 2007; Voss et al., 2009; Verburgh, Scherder, van Lange and Oosterlaan, 2014). The central executive (coordinating attentional activities and selecting action; Baddeley, 2003) in working memory performs on-line analysis and manipulation of information from the phonological loop (holding verbal and acoustic information), visuospatial sketchpad (holding visual and spatial information), and episodic buffer (binding information from the phonological loop, visuospatial sketchpad and long-term memory into unitary episodic representation).

Different working memory tasks activate different areas of the brain, typically with input from both the limbic and cognitive systems. This is underpinned by function in the dorsolateral prefrontal cortex (DLFPC) of the frontal lobe - suggested as a neural correlate for working memory and a crossroads for the shared functioning of the limbic and cognitive systems (Knudsen, 2007; Dietrich, 2004). Verbal working memory tasks that involve the phonological loop typically activate areas that include the DLPFC, the ventrolateral, temporal and parietal cortexes (Aboitz, Aboitz and Garcia, 2010; Welshon, 2010). Visual and spatial working memory tasks that involve the visuospatial sketchpad tend to be supported by activities in the DLPFC, the inferior parietal cortex and occipital cortex (Knudsen, 2007). Tasks that require reference to long term memory utilise the episodic buffer, which involves memory structures such as the hippocampus (Wirth, Yanike and Frank et al., 2003) and basal ganglia, whilst also supported in the DLPFC (Dietrich, 2004).

Due to the role of working memory in perceptual-cognitive skill, there appears to be interest within the literature to minimize the amount of working memory activation (see Just and Carpenter, 1992; Conway, 1996; McCutchen, 1996; Waters and Caplan, 1996) when performing actions (Williams and Ericsson, 2005; Furley and Memmert, 2010). This creates room for more information to enter working memory (Williams and Ericsson, 2005; Furley and Memmert, 2010) and allows for actions to take place using less working memory activation, i.e. with greater efficiency, which relates to Gabbett and Masters (2011) mention of an “economy of action”. In sum, the efficient use of limited working memory capacity can be associated with successful actions.

The “economy of action” mentioned by Gabbett and Masters (2011) relates to the learning and performance of implicit motor skills (Masters 1992; also referred to as procedural knowledge– see Maxwell et al., 2003; Furley and Memmert, 2010), on the basis that implicit skills require little or no activation in working memory, which in the context of using working memory activation makes implicit skills more efficient. This is because implicit skills are integrated subconsciously from long term memory through the episodic buffer and require less or no activation in working memory compared with explicit (or declarative – see Furley, 2010) actions that are handled consciously (Masters et al., 2008; Verburgh et al., 2016; Buszard and Masters, 2017). There is evidence that actions don't rely solely on either system, rather, actions require a combination of the two systems at the same time, facilitated through function in the DLPFC (Dietrich, 2004; Jackson and Farrow, 2005). This means that actions cannot be considered as completely implicit or explicit, rather, actions could be considered implicit or explicit based on the weighting towards each system in performing the action. Even with this distinction, the consensus, based on the literature, is that actions relying more on the implicit system use less activation in working memory and can therefore be a component of achieving an "economy of action".

Greater available working memory capacity plays an important role in performance, due to increased resistance to "Choking" (Bijleveld and Veling, 2014) and relationship with "Flow" (Dietrich, 2004). "Choking" is associated with situations where conscious processing of external information linked with anxiety or stress responses (Schmader and Johns, 2003), reinvestment (Masters and Maxwell, 2008) or distraction (Beilock, 2008) can overload or limit available working memory. The conscious processing of these responses requires activation in working memory (Eysenck and Calvo 1992; Derakshan and Eysenck, 1998; Furley and Memmert, 2010), which reduces the available working memory capacity for action. Because our mental resources are limited at any given moment in time, the reduction in working memory capacity can lead to a breakdown in action (Yu, 2015).

In contrast, Flow is associated with being a state of optimal arousal, allowing the best performance of actions to occur, giving the appearance of effortless performance (Dietrich 2004). Flow is described as a state where implicit skills are applied without interference from the explicit (or conscious) system. Associated with hypo-frontality (Dietrich, 2004), Flow is characterized by many features (explored later in this Chapter) that include lack of self-consciousness and the absence of any fear of failure (Csikszentmihalyi, 1996).

Both the Flow and Choking concepts relate to available working memory capacity and the underlying (implicit or explicit) processes of action, providing an underpinning to the concept of “economy of attention” and “economy of action” in expert performers (Gabbett and Masters, 2011). This concept is used to describe the efficient use of working memory in action (Williams and Ericsson, 2005; Furley and Memmert, 2010) and this chain of thought and evidence through the literature provides a clear association between working memory, perceptual-cognitive skill and expert performance in sport.

In support of the literature presented above, several studies have made a connection between perceptual-cognitive skill and expert performance in sport (Ward et al., 2003; Williams and Ericsson, 2005; Williams et al., 2005; Caserta, 2007; Mann et al., 2007; Williams et al., 2011; Pruna and Bahdur, 2016). This included transferability between sports (Vestberg et al., 2012), comparisons between different athletes (Voss et al., 2009) and ability prediction (Ward and Williams, 2003) – therefore validating the evidential and theoretical link between working memory and performance. Furthermore, Ward (2003) noted that there is a possibility of executing training based on the same functions. This is explored is section 2.2.

This section serves as an introduction to the field, with each subject area explored in the following discussion, starting with working memory and executive functioning.

2.1.2 Working memory and executive function

According to the literature, executive functions are responsible for managing functions such as perception, attention and working memory (Williams, 2000; Mann et al., 2007; Voss et al., 2009; Vestberg et al., 2012; Faubert and Sidebottom, 2012; Verburgh, et al., 2014). Following on from the introduction to this Chapter, where perception and attention are accounted for as being related to, and underpinned by working memory, it is logical to link executive function to the actions of the central executive in working memory (Vestburg et al., 2012), as both are mediated by the DLPFC (Dietrich, 2004). There is an allowance for the link between executive functioning and different forms of consciousness (Dietrich, 2004), but this contextualization can be argued based on the role of the central executive. Specifically, the central executive integrates the input from the other components of working memory (visuospatial sketchpad, phonological loop, episodic buffer) and interprets the input to select an action (Baddeley, 2003). Vestberg et al., (2012) describes this process as on-line analysis and comparison with stored information in order to guide decision making.

One of the functions of the central executive is attentional allocation (Awh, Jonides, and Reuter-Lorenz, 1998; Williams, 2000; Soto, Heinke, Humphreys, and Blanco, 2005; Mann et al., 2007; Huang and Pashler, 2007; Voss et al., 2009; Vestberg et al., 2012; Faubert and Sidebottom, 2012). A prominent theory linking working memory and attentional allocation is biased competition theory (BCT, Desimone and Duncan, 1995). According to BCT, working memory can influence the use of information from the perceptual system by biasing the allocation of attention to the object whose representation matches that held in working memory, for example, allocating attention to the position of an opponent based on cues retrieved via the episodic buffer (Anderson, Matessa and Lebiere, 1997; Logan and Gordon, 2001; Furley and Memmert, 2010). Further to this, stronger sensory inputs may be filtered out in favor of weaker sensory inputs, based on the content of working memory (Anderson et al., 1997; Logan and Gordon, 2001; Furley and Memmert, 2010, 2013). Knudsen (2007) describes this as a comparison of signal strengths based on top-down signal modulation in combination with bottom-up capture of attention by salient stimuli. In-action, BCT can be observed, for example, within the choice of passing a ball to a marked or unmarked opponent (Furley and Memmert, 2013).

The stimulus-driven bottom-up processing involved in BCT is automatically controlled by a number of mechanisms, one of which is inhibition (Knudsen, 2007). Inhibition, in this context, refers to how neural networks can increase their sensitivity whilst decreasing the sensitivity of opposing neural networks (Treue and Martinez Trujillo, 1999; Reynolds and Desimone, 2003; Knudsen, 2007). This process allows subconscious discrimination between stimuli to take place by allowing stimuli that correspond to the neural networks with increased sensitivity to enter working memory, with the relevant neural networks exhibiting a discharge in the process (Knudsen, 2007). Furthermore, Bisley and Goldberg (2003) propose that this competition is not decided by an absolute amount of sensitivity in the networks, rather, it is based upon the relative sensitivity between competing networks. Therefore, depending on the type of stimuli, entry into working memory could be managed by any component of working memory. For example, the visuospatial sketchpad would incorporate the stronger relative stimuli from networks in the inferior parietal and occipital cortexes that correspond to visuospatial stimuli (per Knudsen, 2007); whilst the episodic buffer would incorporate the stronger relative stimuli from networks in the basal ganglia and hippocampus that correspond to procedural cues (per Wirth et al., 2003 and Dietrich, 2004 respectively). Once the stimuli enter working memory, top-down signal modulation (i.e. the central executive) in the DLPFC further discriminate between competing stimuli before allocating attention (Knudsen, 2007). The speed and efficiency of these processes could affect the executive function and actions of an athlete when competing, with experts being able to effectively handle a higher number of stimuli at a much faster rate and higher quality signal strength when compared with novices (Ward and Williams, 2003).

In summary, attention and perception are processes that contribute to decision making and executive functioning and can be contextualized within working memory as functions of the central executive (Williams, 2000; Mann et al., 2007; Voss et al., 2009; Vestberg et al., 2012; Faubert and Sidebottom, 2012; Verburgh, et al., 2014), as both are supported by the same neurological infrastructure (Wirth et al., 2003; Dietrich, 2004; Knudsen, 2007). The central executive manages the input and use of information into working memory and support decision making based on this input (Baddeley, 2003; Baddeley, 2007). These functions are linked to attentional allocation (Awh et al., 1998; Williams, 2000; Soto et al., 2005; Mann et al., 2007; Huang and Pashler, 2007; Voss et al., 2009; Faubert and Sidebottom, 2012; Vestberg et al., 2012) and subsequently, BCT (Desimone and Duncan, 1995) and the mechanism of inhibition (Treue and Martinez Trujillo, 1999; Reynolds and Desimone, 2003; Knudsen, 2007). These theories explain how activation in working memory is allocated to a task, based on the input of stimuli that correlate to competing for interconnected neural networks. The speed, efficiency and quality of these processes can help separate expert decision-making from non-expert decision making (Ward and Williams, 2003).

2.1.3 Working memory - input integration

Storing and manipulating temporary information across its four components (central executive, phonological loop, visuospatial sketchpad and episodic buffer), working memory is constantly integrating various inputs to support the decision-making process (Baddeley, 2003; Baddeley, 2007). In reference to the scenarios athletes face in sport, the integrations covered here are the combined input from the visuospatial sketchpad, the episodic buffer, and the central executive. To understand the input into the visuospatial sketchpad, we need to understand how visuospatial input is gathered, as this shapes the types of input represented in working memory. Therefore, we also need to understand how input from the episodic buffer is selected and integrated, before summarizing the interaction between all three components. To complete the review of input integration into working memory, the integration of motor skills (including motor learning) will be covered in section 2.1.4.

2.1.3.1 Visual Search

When describing effective visual search strategies, Mann et al. (2007) refer to an individual’s ability to visually extract meaning efficiently and effectively in an environment. Voss et al. (2009) note that, in reference to athletes, experts consistently perform better in visual search when compared to non-experts, leading to subsequent differences in the processes of decision making, anticipation and spatial memory. This is supported by the findings of Vestberg et al. (2012) who found a positive correlation between visual discrimination and expertise in soccer. Visual search in the literature includes several concepts – visual fixation (Bar-Eli and Raab, 2006; Knudsen, 2007; Verburgh et al., 2014), centralized gaze (Williams, 2002; Faubert and Sidebottom, 2012) and quiet eye (Bar-Eli and Raab, 2006; Verburgh et al., 2014) – with a further link to spatial attention.

According to Mann et al. (2007), when participants perform a visual search task, measuring the number and duration of their visual fixations makes it possible to record the point of interest and relative attention allocation of an individual. Longer and fewer visual fixations are suggested as an indication of more information being extracted (Mann et al., 2007), and have been used to differentiate experts in team sports (soccer and hockey) from non-experts (Verburgh et al., 2014). Information is not necessarily taken from the locus of these fixations, as signals from working memory orient gaze towards an object and optimize the resolution of the gaze at its fixation, subsequently allowing a spread of attention around the locus of fixation. This spread of attention then allows information in the area around the fixation to be extracted (Faubert and Sidebottom, 2012). In the context of football, this gives an athlete the opportunity to read the body language cues of multiple opponents whilst looking at the ball and use this information to manipulate and plan actions. Knudsen (2007; with reference to Shephard et al., 1986) further describes the underlying functions as a process where, prior to an eye movement taking place, the sensitivity to stimuli at a new locus of fixation is increased. According to Knudsen (2007), this is a reason why gaze control is closely linked to spatial attention, as it provides the basis by which spatial information (through cues) can be extracted from stimuli and used to inform subsequent decision making.

As visual search is completed during an action, the final observable visual process that occurs during an action is referred to as “quiet eye” (Mann et al., 2007; Vickers, 2012;). Quiet eye is noted in the literature as a period between the last visual fixation and the initiation of a subsequent movement. It’s during this time that motor planning of an action (if required) is coordinated (Vickers, 1996; Mann et al., 2007) who defined the end of quiet eye as the beginning of a subsequent motor action, therefore indicating that motor planning would take place during quiet eye. Prolonged quiet eye periods are associated with the extraction of larger amounts of information (Mann et al., 2007) and have been used to demonstrate performance differences between experts and non-experts (soccer and hockey –Mann et al., 2007; Verburgh et al., 2014).

2.1.3.2 Input from long term memory

Alongside input from the visuospatial sketchpad, the next working memory construct considered to provide critical input into working memory for athletes is the episodic buffer. The episodic buffer is the link between long term memory and working memory (Baddeley and Andrade, 2000; Baddeley, 2003; Baddeley, 2007), and in reference to sport, allows the combination of declarative memory (Williams and Ericsson, 2005;Voss et al., 2009) and cue recognition (linking to procedural memory - Williams et al., 2001; Williams and Ericsson, 2005; Mann et al., 2007) - described by Rowe and Mckenna (2001) as domain-specific experience. This was further suggested by Rowe and Mckenna (2001) as, alongside training, a predictor of anticipatory skill. Declarative memory is described as knowledge that can be articulated and explained to others (Furley and Memmert, 2010; Maxwell et al., 2003).

Maxwell et al. (2003) refer to declarative knowledge as a set of rules that are used to guide executive decisions. These processes take place primarily in the cognitive system, in contrast to procedural knowledge, which is mediated primarily by the limbic system (Knudsen, 2007; Dietrich, 2004). Procedural knowledge is noted as knowledge that we cannot necessarily describe or articulate and controls behavior without conscious awareness (Maxwell, et al., 2003; Dietrich, 2004; Furley and Memmert, 2010) - therefore, occurring with less need for working memory activation (Masters et al., 2008).

Cue recognition allows an athlete to gain meaning from an environment and choose appropriate action (Mann et al., 2007). Cue recognition allows access to procedural knowledge in long term memory, allowing automatic action by the athlete that can be independent of working memory activation (Mann et al., 2007; Caserta, 2007; Masters et al., 2008). Therefore, effective and efficient actions can be related to the speed at which procedural knowledge is enacted, as well as the environmental relevance of the procedural knowledge used – i.e. incorrect cue recognition would lead to applying procedural knowledge that is not the most effective action for a situation. It could be suggested that the effective and efficient use of procedural knowledge, as part of a decision-making process, is also indicative of an effective and efficiently used episodic buffer within working memory. It is not possible for declarative systems to process the kind of information that encompasses procedural knowledge, as both systems rely on different types of signals (Maxwell et al., 2003) and it is noted that procedural knowledge does not always require activation in working memory (Caserta, 2007; Mann et al., 2007). However, sport is an example where conscious decision making can be accompanied by a motor action (Masters et al., 2008), therefore it is desirable that motor actions be derived from procedural knowledge in reference to conscious processing of a decision in working memory, as covered later in section 2.1.4.1.

Finally, it should be noted that the processes of declarative and procedural knowledge are interdependent during action (Jackson and Farrow, 2005) as knowledge from each system can occur in response to the other, and actions appear to have a weighting between each system.

2.1.3.3 Working memory – summarizing input integration

Working memory is a structure that supports the temporary storage and manipulation of information required to make decisions, including memory, visuospatial and phonological input (Baddeley and Andrade, 2000; Baddeley, 2003; Baddeley, 2007). This section focused on visuospatial and memory input, as these two forms of information explain how we understand a situation and use a skill in response. Visual search describes how we gather visuospatial information from the environment (Mann et al., 2007) and has been shown to differentiate experts from non-experts in sport (Voss et al., 2009). This differentiation is due to differences in efficiency, with experts using fewer visual fixations (Bar-Eli and Raab, 2006; Verburgh et al., 2014) whilst taking in more information located around these fixations to inform decision making (Faubert and Sidebottom, 2012), demonstrated by the prolonged "quiet eye" periods observed in experts during performance (Bar-Eli and Raab, 2006; Verburgh et al., 2014).

The function of memory input is dependent on the type of information (declarative or procedural) being used, with each type of input being supported by the cognitive or limbic system of the brain respectively (Dietrich, 2004; Knudsen 2007). These types of knowledge have been shown to be interdependent, with declarative knowledge providing a point of reference for procedural knowledge (Jackson and Farrow, 2005). The use of stored information in working memory is based on the recognition of environmental cues, followed by the retrieval of relevant knowledge that will inform a response to those cues (Mann et al., 2007; Caserta, 2007; Masters et al., 2008).

The following section describes how motor skills interact with, and are part of, these processes.

2.1.4 Motor skill acquisition and the relationship of motor skills with working memory

As noted by Maxwell et al. (2003), during performance in sport, information from the environment is perceived by the athlete, leading to a decision on a course of action and the integration of a motor output that is in line with the outcome sought by the athlete, described simply as Perception, Decision Making and Execution in Cross et al. (2013) and O'Connor et al. (2018). To understand the integration of motor skills into working memory and subsequently, decision making, there are two concepts that need to be discussed. The first concept discussed will be motor skill acquisition (motor learning), as the type of motor skill acquisition (explicit/declarative, implicit/procedural) directly affects how acquired skills will interact with working memory when performed (Masters et al., 2008; Furley and Memmert, 2010; Gabbett and Masters, 2011). The second concept discussed will be the performance of motor skills and their relationship with working memory, leading to a discussion of Choking and Flow. The following discussion will also give an overview of the interaction between neural structures that support working memory and motor skill.

2.1.4.1 Types of motor skill acquisition

When discussing motor skill acquisition, the different types of acquisition possible need to be understood. Explicit skill acquisition is linked to declarative knowledge (Maxwell et al., 2003; Furley and Memmert, 2010) which, according to Jackson, Ashford and Nosworthy (2006), is knowledge that can be articulated. Conversely, implicit skill acquisition is linked to procedural knowledge, described as knowledge that cannot be articulated and is presented like an "automatic" response (Masters, 1992; Williams et al., 2001; Williams and Ericsson, 2005; Mann et al., 2007). These types of learning occur through different processes, however, both types of knowledge are thought to be interdependent (Jackson and Farrow, 2005). This interdependence means that the type of learning that contributes to explicit and implicit skills provides a weighting towards each system, rather than exclusive learning within one type of knowledge (though exclusive learning through one system is thought to be possible in rare cases – see Dietrich, 2004). Traditionally there was an expectation that knowledge progressed in a linear process from explicit to implicit (declarative to procedural, or cognitive to autonomous – see Masters, 1992), however it is now understood that implicit skill acquisition can take place immediately by avoiding the contribution of working memory to the learning of a skill, referred to as "implicit learning" (Masters, 1992; Liao and Masters, 2001; Masters, et al., 2008; Gabbett and Masters, 2011). Therefore, explicit skill acquisition can be understood as learning that requires the contribution of working memory.

Implicit skills are suggested to be faster than explicit skills (Masters, 1992; Masters et al., 2008), as well as possessing superior stability (less risk of break down in performance) under pressure, fatigue and multi-tasking (Gabbett and Masters, 2011). It has been noted that implicit skills can require little to no activation in working memory (Liao and Masters, 2001; Rowe and Mckenna, 2001; Williams and Ericsson, 2005; Masters et al., 2008; Furley and Memmert, 2010) relating to the concept of an "economy of action" mentioned by Gabbett and Masters (2011) and the idea of "automatisation in expertise" (Rowe and Mckenna, 2001). Masters et al. (2008) also suggest that by encouraging efficient motor control, implicit skills allow stable performance in situations where constraints require a complex decision to integrate with a motor action. An example of constraints and complex decision making are team sports where time and space are limited and factors such as fatigue and pressure can influence performance (Masters et al., 2008; Verburgh et al., 2016; Buszard and Masters, 2017).

To achieve implicit skill learning, several concepts are noted in the literature, such as dual task (Furley and Memmert, 2010; Furley and Wood, 2016; Buszard and Masters, 2017) and constraint-based learning (Masters et al., 2008; Williams et al., 2011; O'Connor et al., 2017; O'Connor et al., 2018), supplemented by feedback methods that circumvent working memory, such as analogy-based instruction and feedback (Liao and Masters, 2001; Poolton et al., 2006; Lam et al., 2009). In any case, as suggested by Dietrich (2004), multi-dimensional tasks that comprise more than one rule in their solution encourage implicit learning, as the explicit system is not capable of handling many multiple rules in a task consciously. In contrast, explicit learning takes place easily in tasks that encompass a single or a series of sequential rules (Dietrich, 2004).

2.1.4.2 Implicit and explicit learning in action

Demonstrating the difference between implicit and explicit learning, Waldron and Ashby (2001) used a categorisation task and found that most participants that were able to score a near perfect score in the task did so whilst being unable the describe the rules that defined success. Waldron and Ashby's result shows the difference in articulation between explicit and implicit learning and supports the idea that multi-dimensional tasks encourage implicit learning. This demonstrates an underlying principle as to why methods such as dual tasking, constraint-based learning or analogy learning are effective – either by preventing the use of working memory on the task (by occupying available resources) or by avoiding the need for working memory in the task. In regard to sport, within a constraints-based approach, the athlete performs actions in response to multiple rules and stimuli constantly, with both success and failure possible. As Maxwell et al. (2003) suggest, this creates a situation where a hypothesis-testing strategy occurs and develops fundamental explicit rules that guide action. The subsequent actions taken can be considered as implicit skills acting as an application of explicit rules. Conversely, in an exercise with only one rule, for example, repeatedly kicking a ball at a stationary target from the same distance, the task of kicking the ball could be handled as an explicit action in working memory, as there is no other stimulus that requires the use of working memory. Some argument could be made that the above example could create implicit learning using implicit feedback strategies, however, this would still require the active circumvention of working memory in the task, but through the actions of a coach rather than a multidimensional exercise.

Maxwell et al. (2003) propose that the continued application of an implicit learning process within a multi-dimensional task is a process that allows explicit rules to become implicit, therefore over time, guiding a wider range of possible implicit responses with a smaller number of explicit rules. Additionally, Maxwell and colleagues proposed that skill acquisition does not necessarily progress from declarative to procedural, supporting the comments of Furley and Memmert (2010) that learning does not need to make a linear progression from explicit to implicit. Understanding the progression of this learning in practice means that a hierarchy of required explicit rules and implicit actions needs to be understood, therefore allowing effective progressions that encourage previously explicit rules to be applied implicitly in response to a situational task.

It seems possible that the use of tasks that occupy working memory during action could help explicit skills become used implicitly, due to a lack of activation available in working memory that prevents conscious processing of the explicit skill. In contrast, training tasks that involve a large proportion of explicit feedback will use working memory in the learning process (Maxwell et al., 2003) and therefore encourage learning of explicit skills. This is not necessarily negative, as based on the individual, some skills may be better learnt explicitly first. The key here is to understand that the learning would be *weighted* towards the explicit system, not independent of the implicit system. Therefore, in practice, learning can be weighted towards the explicit system just enough for learning to take place, ready for assimilation as an implicit skill later in the learning process. As an alternative to explicit feedback, analogy learning (Liao and Masters, 2001, Lam et al., 2009) is noted as a type of feedback that would be referenced in the visuospatial sketchpad of working memory, with a reference to cues via the episodic buffer. It is thought that this would create an easier transition for skills to become implicit when compared with learning through explicit feedback.

In general, the literature encourages the learning of implicit skills over explicit skills in the context of performance, for reasons such as speed, performance stability and resistance to pressure and fatigue (Masters, 1992; Masters et al., 2008; Gabbett and Masters, 2011; Verburgh et al., 2016; Buszard and Masters, 2017). However, in consideration of the need for explicit rules through the learning process, it is important to emphasise the need to acquire skills implicitly at the *earliest possible opportunity*, rather than assuming all skills can be learned implicitly immediately and without hierarchy or reference point. Again, this suggestion highlights the need to understand the way in which the two systems of implicit and explicit skill acquisition are interdependent (Jackson and Farrow, 2005), as well as how each type of skill can be applied. Finally, it is important to consider the training context of an athlete, there needs to be awareness of the speed at which learning takes place – with explicit learning suggested to be a faster acquisition process than implicit learning (Gentile, 1998), which is contrary to the speed at which each type of skill can be performed once learned. This difference in learning speed becomes important for practitioners who deal with situations where fast learning is required (for example, result-oriented sports teams in-season) versus situations where there is time for a slower learning process (for example, a development-oriented sports team in pre-season).

2.1.4.3 Neural correlates of motor skill acquisition

Motor skill acquisition appears to create activation across several structures of the brain, and the relationship between these structures can help explain why acquisition works in the ways outlined in previous sections. Neuroimaging studies have shown that during skill acquisition, activation is evident in the PFC, premotor cortex, parietal cortex and cerebellum (Jenkins, Brooks, Nixon, Frackowiak and Passingham, 1994). Specifically, in the acquisition of motor skills, the primary motor cortex is also involved (Krings, Topper and Foltys et al., 2000; Luft and Bruitrago, 2005). During this process it is thought that the basal ganglia, as part of a circuit including the hippocampus and supplementary motor cortex, activates passively as an “observer”, and over time increasingly controls details of the process (Mishkin, Malamut and Bachevalierm, 1984; Gazzaniga, Ivry and Mangum, 1998) which eventually results in total control of the task, freeing up working memory to deal with other explicit tasks (Dietrich, 2004). Therefore, on a functional level, this structural relationship explains how skills could start as explicit and become more implicit over time.

The above observations in the literature were made earlier than those within some of the literature on implicit learning, however, it is reasonable to hypothesise that by circumventing, limiting or preventing the use of working memory during learning, activation of the basal ganglia and the associated circuit could compensate. The control of implicit motor skills by the basal ganglia helps explain the sense of automacity when performing implicit actions or using implicit knowledge, as this control is taking place within a subconscious circuit. Given the passive role of the basal ganglia during the motor acquisition process, it is logical that implicit skill acquisition should take longer than explicit skill acquisition, as noted in Gentile (1998). This further reinforces the idea that skills can be learnt as a combination of implicit and explicit knowledge (per Jackson and Farrow, 2005), the weighting towards each system depending on the individual and the method of learning. The following section explains how this combination of implicit and explicit learning interacts with working memory.

2.1.4.4 Integration of explicit and implicit motor input into working memory

Mentioned previously, the type of motor skill acquisition that takes place has a subsequent effect on how working memory is utilized during action. Whilst it is not clearly understood what part of working memory deals with motor input (Buszard and Masters, 2017), it is understood that the performance of explicit motor skills requires activation in working memory (Maxwell et al., 2003; Dietrich, 2004), whilst implicit motor skills may not (Masters, 1992; Dietrich, 2004; Masters et al., 2008; Furley and Memmert, 2010). Given that the two are interdependent (Jackson and Farrow, 2005), it is fair to suggest that the more implicit a motor skill is, the less working memory activation is needed, whilst a proportionally more explicit motor skill will require more activation in working memory. Therefore, it is critical to understand the effect on performance when working memory is used more to perform a motor skill, as well the effect on performance when working memory is used less (or not at all) to perform a motor skill. This difference in effects subsequently links to the concepts of Choking and Flow, covered in section 2.1.5.

The motor skills required in sport are more complex and dynamic than those required for every day actions, and in addition, are performed with less frequency and often under the stressors of fatigue, perceived external pressure and/or higher speed (Buszard and Masters, 2017). Therefore, the motor skills required in sport demand different resources and cannot rely only on the retrieval of fully implicit knowledge from long term memory, in fact, as Jackson and Farrow (2005) note, implicit and explicit knowledge appear to be interdependent, suggesting every action is weighted between the different types of knowledge. This idea relates to the concept of top-down cognitive signals controlling bottom-up limbic signals (Knudsen, 2007), suggesting that the explicit proportion of a motor skill allows the adaptation of implicit knowledge to context.

It is suggested that implicit learning can take place immediately when developing a skill by circumventing working memory use (Masters, 1992; Liao and Masters, 2001; Furley and Memmert, 2010), however given that application of a skill appears to require a degree of explicit knowledge (Jackson and Farrow, 2005), and that performance in sport requires the adaptation of existing knowledge to novel situations, there is an argument that there is some explicit knowledge involved in at least guiding, if not performing, motor skills during sport. This then highlights the gap described by Buszard and Masters (2017) – what component of working memory deals with which proportion of a motor skill?

In response to this issue Buszard and Masters (2017) suggest that until this process is better understood, it may be more effective to focus on the role of the central executive in the process, as it is the common and controlling component of working memory. By focusing on the central executive, it could be easier to understand the input of motor skills into working memory as part of the top-down mediation of bottom-up limbic signals by the cognitive system. This would be more understandable because available activation in working memory would allow more resource allocation to the central executive and therefore greater resource for the mediation of bottom-up limbic signals by top-down cognitive signals (Knudsen, 2007), allowing a greater range of adaptable responses to be drawn from the same pool of implicit knowledge using an explicit reference. Furthermore, the constant spatial reference for skill in sport strengthens the point that a better understanding of the relationship between motor input and working memory is required. This links into the work of Furley and Wood (2016) who discuss how sport requires skills to be performed with an external locus of control (i.e. the immediate environment) and contextual interference (Broadbent et al., 2014; O'Connor et al., 2018) that requires the adapted application of learned behaviors.

Put simply, the more activation in working memory that is required to perform a motor skill, the more vulnerable the skill is to performance degradation (Liao and Masters, 2002). This is because any other conscious processing by the athlete will take up working memory capacity. Therefore, the more a motor skill requires working memory activation, the less working memory resource is available for other processing. As a result, if the environment requires more resource in processing information consciously than is left over in capacity from the processing of the motor skill, there must be prioritization by the central executive in allocating working memory resource towards each process. This means that either less information from the environment is processed, creating a degradation in perception and decision making, or, less resource is allocated to performing the motor skill, increasing the chances of degradation in its execution.

Regarding BCT (Desimone and Duncan, 1995), we know that the response to stimuli and entrance of the stimuli into working memory may be determined by interdependent networks of neurons that are sensitive to particular stimuli (Treue and Martinez Trujillo, 1999; Reynolds and Desimone, 2003; Knudsen, 2007). Therefore, when there is a prioritization between motor skills and perception in working memory, the responsiveness of these networks to particular stimuli will determine which process will be prioritized. This is a subconscious process, which means the athlete has little conscious control of the outcome, with limited control over which process is compromised by the overloading of working memory. However, it is important to note that this may also force the athlete to learn a skill with less working memory activation, increasing the role of the basal ganglia in controlling it, and as a result, the skill may become more implicit over time. The difference between implicit learning and degradation of an explicit motor skill may be a delicate balance with respect to overloading working memory.

In contrast to explicit motor skills, implicit motor skills require less or no activation in working memory (Masters, 1992; Dietrich, 2004; Masters et al., 2008; Furley and Memmert, 2010). As a result, implicit motor skills are noted to be faster than explicit motor skills

(Masters, 1992; Masters et al., 2008; Cona, Cavazzana and Paoli et al., 2015), more resistant to external stimuli (Gabbett and Masters, 2011), and better integrated into multi-tasking actions (Dietrich, 2004; Furley and Memmert, 2010). This is because implicit skills require less conscious control and are processed largely in the circuity network of the basal ganglia in the limbic system (Mishkin et al., 1984; Gazzaniga et al., 1998) – as a result they can be integrated into working memory via the episodic buffer as a complete response, as opposed to a response that would still need manipulation in working memory prior to action. This process leaves maximal working memory capacity available for conscious processing of other stimuli.

As Gabbett and Masters (2011) note, less conscious motor processing makes working memory more capable of carrying out the perceptual-cognitive operations that are required during competition. This is further supported by Masters et al. (2008) who, in an experiment comparing explicit motor performance with implicit motor performance in the execution of a low-complexity or high-complexity directed table tennis shot, found that performance disruption only occurred for participants who learned explicitly in the performance of the high-complexity task. In contrast, the implicit learners (who were taught using analogy learning that likely engages the visuospatial sketchpad – Liao and Masters, 2001) experienced no performance disruption in either of the low-complexity or high complexity tasks. These findings give the impression that implicit actions are more desirable from a performance perspective, with the explicit proportion of actions simply acting as a reference by which to adapt implicit actions to context.

2.1.4.5 Motor inhibition

The idea that implicit skills require less working memory activation, leaving working memory capacity for perceptual-cognitive tasks, leads to the concept of motor inhibition. As suggested by Verburgh et al. (2014) and Cona et al. (2015), motor inhibition describes how an athlete can ‘cancel’ a motor skill in exchange for a different skill, in response to changes in the competition environment. This requires a constant perception process during action, which means that there needs to be enough working memory activation available to execute an action whilst simultaneously perceiving environmental changes. The ability to perform motor inhibition has been shown to differentiate highly talented athletes from amateur athletes in soccer with an 89% success rate (Verburgh et al., 2014). A similar result has been shown in fencing (Di Russo, Taddei, Apnile and Spinelli, 2006), baseball (Nakamoto and Mori, 2008), and tennis (Wang, Chang and Liang et al., 2013). Furthermore, a study by Cona et al. (2015) involving ultra-marathon runners and the use of a dual-task paradigm with a working memory task and a prospective memory task showed that the fastest runners were also the best performers in the two concurrent memory tasks. Presumably, better performers in these studies were performing their motor skills more implicitly than those who performed worse, leaving working memory activation available to support motor inhibition function.

Implicit knowledge is processed in the limbic system and interacts with working memory as a “bottom up” signal (Dietrich, 2004; Knudsen, 2007). These bottom-up signals are automatic and unable to control or create explicit knowledge (Dietrich, 2004) and relate to networks of neurons that respond to specific stimuli (Treue and Martinez Trujillo, 1999; Reynolds and Desimone, 2003; Knudsen, 2007). The act of motor inhibition means that a “top-down” signal from the cognitive system (conscious processing – Dietrich, 2004; Knudsen, 2007) is mediating the “bottom-up” signals, this therefore requires working memory to be available for motor inhibition to take place.

Based on the concept that skilled athletes can be differentiated by their ability in motor inhibition, it can therefore be proposed that skilled athletes have greater available working memory capacity for the retrieval, mediation and adaptation of bottom-up signals and implicit/procedural knowledge during competition when compared with lesser skilled athletes. This proposition holds clear implications for the development of expertise in sport – that retrieval and contextual adaptation of implicit/procedural learning, supported by increased available working memory capacity, appear to be pivotal in determining expertise.

2.1.4.6 Summarising motor acquisition and the integration of motor skills into working memory

This section explored the acquisition of motor skills and their input into working memory as part of the decision making and skill execution process. Motor skills are acquired as part of an interdependent process (Jackson and Farrow, 2005), weighted between implicit (procedural) and explicit (declarative) knowledge, with the context or method of acquisition weighting a skill towards either type of knowledge. These types of knowledge have different working memory demands, with implicit knowledge being faster (Masters et al., 2008), more stable (Gabbett and Masters, 2011), and requiring less activation than explicit knowledge (Liao and Masters, 2001; Rowe and Mckenna, 2001; Williams and Ericsson, 2005; Masters et al., 2008; Furley and Memmert, 2010). Multidimensional tasks encourage implicit learning, as explicit systems have a different signal type which can’t handle multiple performance rules, forcing implicit skills/procedural knowledge to be used (Waldron and Ashby, 2001). This principle also applies to analogy learning (Liao and Masters, 2001; Poolton et al., 2006; Lam et al., 2009), and it is noted that implicit learning can be slower to acquire than explicit learning (Gentile, 1998), which may affect practitioners working within time constraints. It is therefore suggested that implicit knowledge should be pursued at the *earliest possible* opportunity, allowing for the management of other factors that could affect the acquisition process. Explicit and implicit knowledge are supported by structures in the cognitive and limbic systems respectively (Dietrich, 2004; Knudsen, 2007), with limbic structures such as the basal ganglia encoding explicit knowledge into implicit knowledge over time, eventually freeing up working memory to use activation for other processes (Dietrich 2004).

Motor inhibition, the ability to “cancel” a motor skill during an action in favor of an alternative (Verburgh et al., 2014; Cona et al., 2015) can differentiate experts from non-experts in sport (Di Russo et al., 2006; Nakamoto and Mori, 2008; Wang et al., 2013; Verburgh et al., 2014). This is controlled by explicit knowledge, using working memory activation to create an explicit top-down signal (cognitive to limbic) that mediates implicit bottom-up signals (limbic to cognitive) (Dietrich 2004; Knudsen, 2007). Despite limitations in the understanding of how working memory processes motor input (Buszard and Masters, 2017), the form of acquisition and consequent integration of motor skills into working memory can influence the performance state of athletes. The following section explores “Choking” and “Flow” as two extremes of performance state, explaining the contributing factors to, and implications of, each state.

2.1.5 Choking, Flow and the role of dopamine

2.1.5.1 Choking

A term used to describe skill degradation under pressure is Choking. Choking is defined by Mesagno and Hill (2013) as an acute and considerable decrease in skill execution, relative to self-expected standards, that is the result of increased anxiety under perceived pressure. Mesagno and Hill (2013) suggest that there appear to be four factors that distinguish Choking from underperformance. These are the magnitude of performance decrement, negative cognitive appraisal of anxiety, decreased perceived control and self-presentational concerns. Further research relating to the presence of an anxiety response in Choking includes Eysenck and Calvo (1992), Derakshan and Eysenck (1998) and Schmader and Johns (2003). In addition, reinvestment (the attempted conscious control of an implicit response - Masters and Maxwell, 2008) and distraction (Beilock, 2008) are also suggested as factors that could contribute to Choking. It is suggested that the anxiety, reinvestment or distraction response takes up enough activation in working memory to overload the system and cause a compromise in performance (Yu, 2015).

In a review paper by Mesagno and Beckman (2017), the mechanisms of Choking were related to two different categories in the literature – self-presentational models and attentional models. Self-presentational models of Choking suggest that personality can increase Choking susceptibility due to increased cognitive anxiety, caused by athletes attempting to monitor and control how they are perceived and evaluated by others (Mesgano and Beckman, 2018), which explains why athletic identity appears to play a key role (Mesagno, Harvey and Janelle, 2011, 2012) in Choking susceptibility. Relatedly, it also appears that factors influencing Choking are not limited to competition-specific factors such as athletic identity. Klein and Boals (2001) found that stress from life events can also create responses that take up activation in working memory, as the athlete might consciously suppress negative thoughts that come from life event stress, subsequently leading to a decrease in available working memory capacity. This idea is further support by the work of Beilock, Jellison and Rydell et al. (2006) who tested the effects of stereotype threat (ST - the effect of negative stereotyping on a population) on skill performance. This study found that ST affected performance due to a reduction in working memory capacity, reinforcing how an overload of conscious/explicit processing can compromise successful function. This finding is consistent with the earlier work of Schmader and Johns (2003), who tested different populations to assess the effect of ST on working memory capacity, finding that the participants scores for working memory capacity were reduced after the negative stereotype was introduced.

The attentional models of Choking mentioned by Mesagno and Beckman (2017) highlight two mechanisms of Choking. First, a self-focus model that refers to the explicit monitoring of implicit processes caused by anxiety, described as reinvestment in Masters (1992) and Masters and Maxwell (2008). Implicit (or procedural) processes are too complex to be processed in working memory and rely on different signals (Maxwell et al., 2003), therefore, when reinvestment occurs, the athlete is attempting to control an action using a system that can't process the action, leading to a breakdown in skill. The second mechanism mentioned by Mesagno and Beckman (2017) is a distraction model, which suggests that under stress, attention may shift to irrelevant cues creating a two-fold issue of perceiving irrelevant information, whilst also limiting available working memory activation for relevant processing. In practical terms, this could lead to two outcomes, either an incorrect decision-making process based on irrelevant cues, or a breakdown in action caused by not having enough working memory activation available to process the correct action.

Based on the literature, interventions that address Choking seem to take two avenues. First, mediating state or trait-related cognitive anxiety during performance, which could be achieved through psychological skill training approaches including mindfulness (Bijleveld and Veling, 2014) or acclimatization strategies (Mesagno and Beckman, 2017). The second avenue for addressing Choking seems to be limiting conscious processing during performance as much as possible, focusing available activation on the few relevant explicit rules that allow retrieval and use of appropriate implicit responses. This could be achieved using implicit skill acquisition strategies such as analogy learning (Liao and Masters, 2001; Poolton, Masters and Maxwell, 2006; Lam et al., 2009) or constraint-based approaches (Furley and Wood, 2016; O'Connor and Larkin, 2017; O'Connor et al., 2018). In summary, Choking seems to be the result of not having enough resources in working memory to process the required action, which can be due to a number of attentional or psychological mechanisms that stem from the influence of state or trait anxiety.

As an aside, Dietrich (2004) alludes to the use of working memory resource in attentional drift, such as daydreaming, when an action doesn't require full working memory resource. If attentional drift contributes to skill breakdown, it could be relevant to distraction models of Choking, even though anxiety is not necessarily related to activities such as daydreaming. This suggests that there is still future work needed to define or distill Choking and skill breakdown, with Mesagno and Beckman (2017) suggesting neural imaging as being critical to creating a better understanding of Choking.

2.1.5.2 Flow

In contrast to Choking, Flow has been described as a state where an individual can apply implicit responses with minimal (if any) interference from the explicit system (Dietrich, 2004). In this state, it is proposed that the implicit knowledge base of an individual is applied as a reflexive process to a situation in a fast and effortless manner. This could appear to be a contradiction to theories of perceptual-cognitive skill that suggest the guidance of a small number of explicit references that guide implicit response (Gabbett and Masters, 2011), however, as Dietrich (2004) suggests, the explicit component of Flow could be the decision by the athlete to focus attention on a task and simply “do”, which in turn relates to further implicit rules and skills. However, both positions could be seen as accurate, as a small number of simple explicit references (a wider range than just “do” – perhaps “plan A” and “plan B”) could refer to a wide range of implicit skills, for example, in the use of analogy learning where one explicit cue is used to execute multiple components of a skill implicitly. Flow therefore requires implicit performance from the athlete in task relevant skills, which in relation to working memory, means activation is mostly utilized for handling a perception of the environment, with less activation used for conscious manipulation of information and decision making.

Interestingly, Dietrich (2004) describes Flow as being consistent with not just implicit knowledge, but a state of hypo-frontality, where the PFC is inhibited in favor of activation in limbic structures, therefore limiting explicit function. This theory is based on the finding that individuals who experience Flow describe the state as automatic and without any conscious thinking – which suggests that Flow state requires less function from the PFC. This idea is linked with the original work on Flow by Csikzentmihalyi (1996) who listed the characteristics of Flow as below:

1. Clear goals of action at each moment of performance
2. Immediate feedback to each action
3. A balance between challenge and skill level
4. Merging of action and awareness

5. No conscious distractions

6. No fear of failure

7. Lack of self-consciousness

8. Distortion of time perception

9. The activity becomes autotelic

As a general description based on the above, Flow is a state where actions are performed as an automatic, “in the moment”, self-fulfilling response to a changing environment. It is critical that the qualities of the situation require activation of the implicit system, withnworking memory activation used to simply direct the actions. This would concurrently avoid working memory activation being used to process thoughts that are outside of the action-feedback cycle of Flow. As well as the qualities of the situation, it is important that the athlete can efficiently use working memory activation to let go of irrelevant thoughts that could take up activation, directing/allocating attention only to the task at hand (Dietrich, 2003). This idea is supported by Ross, Tkach and Ruggieri et al. (2003), who found that increased performance in a golf task was related to decreases in cognitive activation (i.e. the hypofrontality described by Dietrich). Dietrich (2004) comments that this is linked to focused attention during task performance, using working memory to stay focused on one element and block out any thoughts that could reduce working memory capacity. Dietrich (2003) summarises that the opposite, allowing attention to drift, would allow working memory capacity to be taken up by irrelevant thoughts or stream of consciousness, such as daydreaming, and therefore be detrimental to the clear goals and actions required within the principles of Flow outlined by Csikzentmihalyi (1996).

2.1.5.3 The role of dopamine

The responsiveness of an individual's dopamine system seems to influence Choking, Flow, and the idea of working memory capacity as a predictor of performance (Cools and Robbins, 2004; Bijleveld and Veling, 2014). The dopamine system has been shown to manage risk-taking behavior and is associated with either efficient or inefficient function of working memory (Bijleveld and Veling, 2014). Cools and Robbins (2004) explain this relationship between dopamine and PFC control as an inverted-U hypothesis, shown in Figure 2.1.

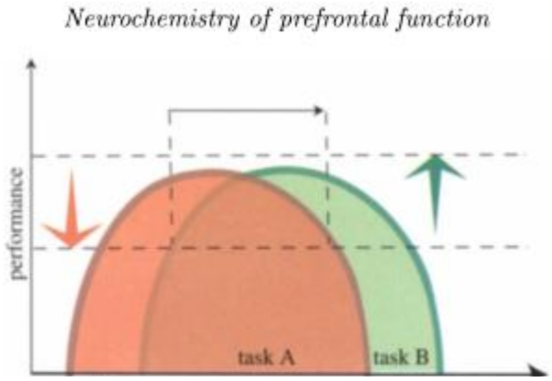


Figure 2.1 Relationship between dopamine and performance as an inverted U hypothesis (Cools and Robbins, 2004)

Figure 2.1 proposes that once dopamine reaches a certain level, the PFC (conscious processing, working memory) no longer has control of neural activity (Arnsten, 2009). This means neural activity becomes too controlled by the bottom-up processes of the limbic system at high dopamine levels, compared to low dopamine levels that lead to too much control by the top-down processes of the cognitive system.

In relation to performance, this inverted-U hypothesis indicates that dopamine levels at either end of the scale could cause skill execution in explicit, one-dimensional tasks to become more difficult, or in multi-dimensional tasks, the executive control of implicit actions to decrease, making decision making more difficult. Alternatively, over activation of the PFC in relation to the limbic system could take place, in which case the individual could experience an explicit stream of consciousness that isn't linked to any implicit action. It has been suggested that focusing attention can help avoid this effect (Ross et al., 2003; Dietrich, 2003; Dietrich, 2004), however, the more extreme the dopamine response, the more skilled the athlete must be at focusing attention.

It is suggested by Bijleveld and Veling (2014) that in using working memory capacity as a predictor of skilled performance, it needs to be considered whether the responsiveness of an individual's dopamine system can reduce the predictive nature of working memory capacity. Less responsive dopamine systems could allow a more consistent level of performance that can be predicted by working memory capacity, as opposed to more responsive systems that may increase the probability of an athlete adapting or applying skills incorrectly. As a result, Bijleveld and Veling (2014) suggest that psychological skills training can be used to mediate the sensitivity of the dopamine system. For example, a mindfulness approach for individuals whose low dopamine sensitivity relates to a top-down dominated state, or conversely, the use of pressure situations in training that require the direction and control of attention for individuals whose high dopamine sensitivity relates to a bottom-up dominated state.

2.1.5.4 Summarising Choking, Flow, dopamine and performance

As a summary, it can be suggested that implicit motor skill acquisition (Masters 1992, Liao and Masters 2001; Masters et al., 2008; Furley and Memmert, 2010) with appropriate (relative to dopamine sensitivity – Bijleveld and Veling, 2014; Cools and Robbins, 2004) psychological skills training is a method by which practitioners can limit the probabilities of Choking occurring, whilst increasing the probabilities of Flow state occurring. It can be argued that athletes who benefit from the process will be more successful more often, due to frequent performances in Flow state and high resistance to circumstances such as pressure and stress. Furthermore, it is clear that not only is greater available working memory capacity a potential predictor of performance, but the efficient use of available capacity and the sensitivity of an individual's dopamine system are additional factors.

2.1.6 Perceptual-cognitive training

Perceptual-cognitive training has been discussed in the literature based on the idea that cognitive abilities can be improved, potentially by developing more efficient neural networks (Voss et al., 2009). In a wider scope, Caserta (2007) discusses the use of perceptual-cognitive training in response to the spatial-temporal challenges that are present in the dynamic environment of sport; speeding up processing and increasing the implicit nature of movements whilst making rapid and accurate decisions. It has been found that the cognitive abilities of an individual are trainable due to the plasticity of the brain, shown in a lab-based pilot study where high-level athletes showed up to a 50% gain in cognitive abilities from training (Faubert and Sidebottom, 2012). These theories have been applied using methods such as dual tasking and constraint-based learning with specific feedback strategies, whilst further research covering the age-relative effects of training has also been covered.

Following the idea that perceptual-cognitive training can be used to improve performance, there is further evidence within the literature that relates to age relative training effects. Research has shown that executive functions such as processing speed, inhibition and working memory continue to develop as athletes age from 12 to 19 years old (Vestberg et al., 2012; Verburgh et al., 2014). As Ward (2003) notes, from as early as 9 years old, skilled athletes can be differentiated from novice athletes by their ability to use and integrate contextual information with stored cues in working memory. Underlying these points, research in rehabilitation has shown that even old-old adults can improve these processes with correct training, albeit at a slower rate further through the lifespan (Smith et al., 2009;

Brehmer et al., 2011; Bastian et al., 2013). The faster learning at younger ages in these areas is thought to be, rather than due to any kind of structural limitation, reflective of faster encoding and a wide variety of alternative strategies during the learning process (Ward and Williams, 2003). Most importantly, the domain-specific knowledge required for expert-level performance is thought to take up to ten years to acquire (Wards, 2003), which, when considered with the age range outlined above, gives a guide on how and when perceptual-cognitive training could be used during the development process to help develop better athletes.

Dual tasking was used by Baddeley and Hitch to investigate working memory and show the relationship between the central executive and associated components (Baddeley, 2007). These studies showed that limited information could be held whilst new information is integrated. During sport, athletes need to be able to integrate high quality motor processes with stored high-quality information, whilst taking in high quality new information – therefore requiring greater perceptual-cognitive abilities that are underpinned by working memory.

The combination of motor skills and decision making requires the ability to multitask effectively, which has been shown to be trainable using dual-tasking conditions (Jackson et al., 2006; Gabbett and Masters, 2011). One study, which involved the participation of experienced and novice football players in dual-task dribbling exercise, found a consistent relationship between experienced players and faster performance in the dual task condition (Beilock, Wierenga and Carr, 2002). This finding was also supported in studies comparing attention allocation and expertise under a dual task condition (Gray, 2004; Ford, Hodges and Williams, 2005). These studies also found that the performance of experienced players was also superior under a dual-task condition when compared to a single-task condition – thought to be caused by a change to more implicit processing of one task to process the secondary task (Jackson et al., 2006). This process is thought to counteract explicit monitoring drifting to process unnecessary or unhelpful information, such as awareness of pressure or fatigue, consistent with causes of Choking, due to the ability of dual-tasking to occupy working memory. However, any successful performance would depend on the difficulty of the dual task, as an overload of working memory capacity is known to cause a performance decrement, as seen in the case of Choking. Therefore, individualized and adaptive training is recommended, as this would provide a balance to task difficulty that would create a training effect with limited performance decrements. Based on these findings, the hypothesis of Rowe and Mckenna (2001) that experts would show less of a decrement in performance under dual-task conditions when compared with novices, is well supported.

2.1.6.1 Dual Task Training and Working Memory Training (WMT)

It is clear from the literature that dual-tasking is an effective perceptual-cognitive training method, however, throughout the literature this has been approached in different ways. Gabbett and Masters (2011) discuss tasks such as counting backwards or forwards in different sequences but found the tasks to be impractical, whilst it is also difficult to assess the difficulty of these tasks in a systemised manner, which makes the recommendation of individualized and adaptive training difficult to prescribe in practice. In the same study, the design of alternative approaches was suggested, supporting the rationale to find methods that integrate perceptual-cognitive training into Football Coaching. Similarly, lab-based training such as the Multiple Object Tracking (MOT) task (Faubert and Sidebottom, 2012) have been utilized. However, the benefit of any domain-specific implicit learning is lost once training is removed from the sporting context itself, which could therefore have lab-based training seen as inefficient. The limits of lab-based methods have been further noted by Faubert and Sidebottom (2012), who comment on the difficulty of testing the application of these methods in practice with elite teams, due to difficult scheduling and existing training processes. This research proposes that WMT can be used as an alternative approach to dual tasking, due to its prescriptive ability, in addition to evidence that it can be used to improve processing efficiency and positively affect brain plasticity, among other outcomes.

On first impression, it may seem that WMT and dual tasking could be the same concept, however, the key difference is that WMT uses tasks that have been shown (with appropriate doses) to affect plasticity, whilst the methods of dual task training in the literature don’t have the same evidence behind the tasks. Inherently, testing in sports contexts will make it difficult to discriminate between practice effects that are caused by an increase in plasticity, or an increase in implicit skill when using WMT as a dual task, due to the focus on skill performance, which is multifactorial. This makes research on WMT as a dual task difficult, as it may be unclear how measurements can discriminate between practice effects that stem from changes in working memory efficiency or available capacity. The first solution is to track changes in both skill performance and working memory performance, with those results informing discussion that helps understand the influences of dual tasking and/or WMT.

There is extensive literature discussing the impact of dual tasks (for a review see Koch, Poljac, Müller and Kiesel, 2018), especially in the context of implicit motor learning (Masters, 1992; Maxwell et al., 2001; Liao and Masters, 2001; Gabbett and Masters, 2011; Buszard and Masters, 2017) however, there is no sport-specific research investigating skill performance or development where WMT is used as a dual task, so a comparison is difficult to make until further work is done. Despite the difficulty in understanding how each component of a dual task WMT intervention would influence performance effects, the idea that training could influence implicit learning (impacting working memory efficiency) whilst simultaneously developing working memory capacity seems positive. This is because, in theory, such an approach would force actions to be carried out implicitly, whilst capacity for future actions and the adaptation of those actions would also be developed. The impacts on implicit learning and adaptation would allow performance to be developed faster, as the ability to learn and perform future actions is prepared prior to further learning taking place. To reference the analogy used in the introduction to this thesis, this approach would mean hardware is being built in preparation for new software, whilst existing software is simultaneously improved, as opposed to simply developing new software on the same hardware.

To conclude, it is unclear from the literature whether using WMT as a dual task would specifically influence working memory capacity or efficiency, it but it may be possible that it influences both. This is also dependent on the perspective of researchers, as it could be argued that dual task training (in the context of implicit motor learning research) influences efficiency due to less working memory activation being required during action. Conversely, it could be argued that dual tasks influence capacity by leaving a greater amount of capacity available during action.

WMT and dual tasks aside, the discussion of working memory capacity versus working memory efficiency is a theme that is further informed in section 2.2, with studies using brain imaging in sections 2.2.2 and 2.2.3 pointing towards an impact on efficiency, rather than capacity, related to changes in processing speed in the prefrontal cortex (Dux, Tombu, and Harrison, 2009; Jolles, Grol, Van Buchem, Rombouts and Crone, 2013) that seem to be linked with a decrease in activation (Schneiders et al., 2012). Sport specific research using WMT as a dual task is required to better understand the relationship between WMT, dual tasking, working memory capacity and working memory efficiency, and future studies should consider attempting to delineate dual task and WMT effects.

2.1.6.2 Constraints-based approaches

Alongside the use of dual-tasking as a perceptual-cognitive training method, constraints-based methods have been mentioned in the literature as a means of perceptual-cognitive training, although it's mechanisms may make the approach appear to be passive or indirect. Constraints-based training involves the manipulation of game-based training conditions (such as player numbers, field dimensions and rules), which creates both random and variable practice through contextual interference (O'Connor and Larkin, 2017; O'Connor et al., 2018) in response to multi-dimensional tasks (per Waldron and Ashby, 2001). Constraints based training also has the advantage that it can replicate the actions and tasks required for performance in competition (O'Connor et al., 2018), with reference to a system of play (Cross et al., 2013) and allowing coaching styles such as guided discovery to be used (O'Connor et al., 2017).

In contrast to dual tasking (with or without the use of WMT), which is designed to occupy working memory over and above the actions required in performance, constraints-based approaches are related to principles of implicit skill learning. This means that in any given exercise there is a multidimensional task, whilst instruction from coaches is encouraged not to be verbalized or broken down in an explicit way – which has implications for the use and timing of questioning approaches in coaching – as the exercises use an external locus of control (Furley and Wood, 2016) which relies on implicit feedback. As Gabbett and Masters (2011) suggest, such methods sit within a wider culture that allows instinctive, intuitive and implicit behaviors to become the solution to training-created problems. This contrasts with the socially constructed view of what traditional coaching might look like in practice, which as Gabbett and Masters (2011) note, can create challenges in its application.

2.1.6.3 Summarising perceptual-cognitive training

Based on the discussion of motor learning, subsequent input into working memory as an underpinning structure to perceptual-cognitive skill, and therefore expertise, it is suggested that an approach that combines implicit skill learning with appropriately prescribed WMT and dual tasking could help improve performance in sport. Furthermore, as Faubert and Sidebottom (2012) suggest, there has been no application of the progressive overload principle seen in physiology to methods of cognitive training, which could seem strange given that individulised adaptive training (a theme prevalent in coaching literature) has been explored. A potential training process of perceptual-cognitive skill, combining dual tasking and constraints-based learning with a progressive overload of working memory using WMT, will be further explored as part of the methodology in this research, with concepts from the field of WMT applied and evaluated.

2.1.7 Summarising the link between Working Memory and sports performance

Effective use of greater available working memory capacity differentiates experts from non-experts in sport due to differences in perceptual-cognitive processing efficiency and speed (Mann et al., 2007; Voss et al., 2009; Vestberg et al., 2012; Verburgh et al., 2014). This is underpinned by the efficient and correctly balanced interaction between the top-down processes of the cognitive system and the bottom-up processes of the limbic system (Dietrich, 2004; Knudsen, 2007) that interact through working memory in the DLPFC (Dietrich, 2004). The increased perceptual-cognitive skill of experts can be determined through an age-specific training process that includes implicit learning strategies (Masters, 1992; Liao and Masters, 2001, Poolton et al., 2006; Lam et al., 2009) such as constraint-based exercises (Maxwell et al., 2003; O’Connor and Larkin, 2017; O’Connor et al., 2017; O’Connor et al., 2018) or dual-tasking (Jackson et al., 2006; Gabbett and Masters, 2011; Cona et al., 2015). WMT could be used as a dual-task, developing implicit skills whilst simultaneously developing working memory, and over the long term, increasing the available working memory capacity of the athlete during performance. In addition, methods that aid the direction and control of attention would need to be used (per Dietrich, 2003) to ensure any newly available working memory capacity is utilised to aid performance.

Previously, the correct prescription of perceptual-cognitive training has been difficult to achieve, and implementation outside of lab-based training has been challenging (Gabbett and Masters, 2011; Faubert and Sidebottom, 2012). WMT research has shown clear guidelines in prescription, and with the right tools can be integrated into practice as a dual task within on-field training. If an integrated approach of WMT, dual tasking, constraint and implicit learning are combined with the management of an individual's dopamine system through psychological skills training (per Bijleveld and Veling, 2014), the probability of a Flow state during performance could be increased, whilst probability of a Choking state could be decreased - therefore increasing performance stability. Conversely, explicit learning, one-dimensional training and non-domain-specific training appear to be methods that negatively impact available working memory capacity during performance, or increase the risk of Choking. This can be due to inefficient use of working memory and imbalance between the interaction of top-down cognitive and bottom-up limbic processes during performance.

In summary, based on this literature review the following assertions can be made:

- Expertise in sport is underpinned by perceptual-cognitive skill, which is dependent on efficient use of available working memory capacity in integrating memory, sensory and motor inputs.

- Efficient use of working memory is dependent on a correct balance between explicit (declarative) knowledge as a top-down process in the cognitive system and implicit (procedural) knowledge as a bottom-up process from the limbic system.
- Flow state is linked with expert performance and is underpinned by efficient use of working memory and the application of implicit knowledge.
- Choking is linked with performance degradation and is underpinned by inefficient use of working memory and the application of explicit knowledge.
- Flow and Choking occur with a relationship to the function of the dopamine system in each individual, which can be managed using psychological skills training.
- Perceptual-cognitive skill appears to be trainable across the lifespan and needs to be correctly prescribed outside of lab-based training, using implicit learning methods such as dual tasking.
- Dual tasking using WMT could be a solution that offers both implicit learning and training of working memory itself in a domain-specific context.

Based on this literature review it appears that a combination of domain-specific implicit learning and using WMT as a dual task could enhance and develop perceptual-cognitive skill. The domain-specific application of WMT as a dual task is central to these assertions and will be investigated within Chapters 3-7.

The following section presents a systematic literature review of WMT, exploring the effect of WMT on neurological structures, processing and task performance, whilst providing insight into the effective application of WMT.

2.2 Working Memory Training (WMT): A systematic review

This Chapter reports the results of a systematic literature review of WMT. Findings and trends from the literature are presented, culminating in the presentation of proposed principles of using WMT. Effects on neurological structures, processing and task performance are included within the scope of this review. The fields of non-adaptive, adaptive, concentrated and distributed training will be explored. Throughout the Chapter, gaps in the research and findings will be highlighted, with the aim of determining how WMT principles will inform the integration of WMT into Football Coaching. The Chapter concludes with a tabulated presentation of research findings.

2.2.1 Data Overview

The literature was reviewed using a clinical methodology. Data were extracted from a total of forty-five studies identified as relevant literature to the present research. These studies were put through a quality appraisal. The quality appraisal required each study to fully comply with the checklist noted in Wright, Brand, Dunn and Spindler (2007), requiring studies to detail elements such as controls, participants, and blinding. Studies that passed the quality appraisal were tabulated for data analysis. The studies included non-adaptive WMT, adaptive WMT and an adaptive/non-adaptive mixed training method (see detailed description below). Concentrated (more than three sessions within a seven-day period) and distributed (three or less training sessions within a seven-day period) training programs were identified within the literature, with mixed use of active and passive controls also present.

The majority of studies included in this review reported a positive association between WMT and working memory task performance. This is found within trained tasks (improvement specifically on the tasks used in WMT) and, in several studies, transfer tasks (improvement found in tasks not specifically carried out within WMT). A small number of studies included were focused on neurological adaptation following WMT. The following populations, both male and female, were within the scope of the literature; Ch (children; 8-11 years; Holmes, Gathercole and Dunning, 2009), YA (young adults; ~20-35 years; Brehmer et al., 2012), OA (old adults; 60-70 years; Brehmer et al., 2011).

2.2.2 Non-adaptive training

The non-adaptive training of working memory is described as a training method where the difficulty of a training task is not adjusted to the success or failure level of the training participant (Persson and Reuter-Lorenz, 2008; Dux et al., 2009; Holmes et al., 2009; Jolles, Van Buchem, Crone and Rombouts, 2010; Jaušovec and Jaušovec, 2012; Jolles et al., 2013). Non-adaptive training was found to illicit both trained task and transfer task gains (Jaušovec and Jaušovec, 2012) when using an N-back task within WMT. This included the finding of Jolles et al. (2010) who found that gains were still evident in testing six months after the intervention. This finding is supported by Jaušovec and Jaušovec (2012), who applied WMT to 15 YA against a control group of 15 YA who were part of a placebo training program. The study used fluid intelligence tests and measured neuroelectric brain activity, finding that the experimental group significantly increased performance on the tests versus the control group (who showed no improvement). Trends in neuroelectric brain activity and changes in site activation, from unbalanced activation of frontal brain areas to a balanced activation of frontal brain areas, led to the conclusion that WMT influenced maintenance functions and central executive processes. This process resulted in a more efficient performance within the tests. In both cases, an N-back task was used in non-adaptive training and test results showed an improvement in the performance of trained and transfer tasks. Further evidence was found in Dux et al. (2009) and Jolles et al. (2013), with both studies reporting changes in frontal activation that led to increased processing efficiency. These studies all show that non-adaptive WMT can create adaptations in the frontal brain leading to performance gains in tests of working memory, as well as tasks that are different to the training itself (transfer tasks).

Dux et al. (2009) investigated the mechanical effects of training, discovering why the increase in processing efficiency was achieved. The study dismissed the notion that training moved processes away from the prefrontal cortex (PFC) to increase processing speed. Rather, training affected the speed of processing in the prefrontal cortex (PFC) itself. This speed increase in the PFC indicated that non-adaptive WMT can create performance-improving adaptations in the frontal region of the brain. Further to this finding, Jolles et al. (2013) used fMRI during performance tests to monitor neural activation. The discovery that connectivity between the PFC and other neural structures was reduced after training supports the notion that training increases the speed of processing within the PFC, as opposed to moving processes to other neural structures (fMRI imaging would have shown increased activation between the PFC and other structures if it was the case). These findings do suggest effects on neurological plasticity – a subject that will be covered later in this review.

Of the non-adaptive studies used in the review, two studies reported no improvement in transfer task performance. Jolles et al. (2010) and Jolles et al. (2013) both used the verbal WMT task developed by Crone (2006) within a concentrated training program and reported no improvement or activation effect within transfer tasks after using the method. No other non-adaptive studies or distributed training studies engaged verbal WMT as a method, therefore further research within distributed non-adaptive training is required to further validate the finding that the verbal WMT method has a negligible effect on transfer task performance.

The use of distributed or concentrated programs within non-adaptive WMT appears to have no effect on the test performance outcome of WMT. Despite this, the extent to which improvement takes place is contestable between the two.

2.2.3 Adaptive training

Adaptive WMT is noted as a methodology where the difficulty of a working memory task is adjusted based on the success ratio of the participant (Olesen, Westerberg and Klingberg, 2004; Dahlin et al., 2008; Jaeggi, Buschkuehl, Jonides and Perrig, 2008; Smith et al., 2009; Chein and Morrison, 2010; Brehmer et al., 2011; Loosli et al., 2011; Takeuchi et al., 2011; von Bastian and Oberauer, 2012; Zimmer, Popp, Reith and Krick, 2012; Penner, Vogt and Stocklin et al., 2012; Brehmer et al., 2012; Schneiders et al., 2012; Chooi and Thompson, 2012; Bastian et al., 2013; Heinzel et al., 2013; Redick et al., 2013). The algorithm for adaptive training dictates that a fifty percent or less success rate means difficulty should be lowered, between fifty and eighty percent difficulty is kept the same, and at eighty percent success or more, the participant should be given the next level of difficulty (von Bastian and Oberauer, 2012; Bastian et al., 2013). These findings are similar to the concept of balancing success and challenge found within sports coaching literature (see Light, 2013).

In studies of adaptive training, all studies provided evidence of trained and transfer task performance gains with varying magnitude. Distributed and concentrated training programs were both present within the studies, including research that tested both methods against each other. In a comparative study of distributed training and concentrated training, Penner et al. (2012) found that distributed training correlated with greater performance gains than concentrated training.

No other studies comparing the effects of concentrated and distributed WMT were found in the literature. Therefore, it is suggested that further research is required to investigate the differences between distributed WMT and concentrated WMT.

2.2.3.1. Concentrated adaptive WMT

Within the field of adaptive training, extensive research into concentrated WMT is present in the literature. Within these studies, concentrated training was shown to elicit only trained gains (Chooi and Thompson, 2012; Redick et al., 2013), as well as both trained and transfer gains (Jaeggi et al., 2008; Smith et al., 2009; Loosli et al., 2011, Brehmer et al., 2011; Takeuchi et al., 2011; Schneiders et al., 2012; Brehmer et al., 2012; von Bastian and Oberauer, 2013; Bastian et al., 2013). The literature associates concentrated training with transfer gains and provides further evidence to claims of WMT increasing neural efficiency (Olesen et al., 2004; Jaeggi et al., 2008; Dux et al., 2009; Brehmer et al., 2011; Schneiders et al., 2012; Jolles et al., 2013). There is also mention of changes in working memory capacity (Jaeggi et al., 2008).

Both Chooi and Thompson (2012) and Redick et al. (2013) found that concentrated WMT created only trained task performance gains – similarly, both studies used a dual N-back task to train participants. Given that many studies found transfer gains were possible using concentrated training, this finding may question the effectiveness of the dual N-back task in these cases, rather than concentrated WMT. Redick et al. (2013) note that despite considerable improvement (Chooi and Thompson also reported a 34% improvement within eight days of training) in the performance of the dual N-back task, positive transfer to other cognitive ability tests was not apparent in the data. The use of the dual N-back task is relevant, considering that its use in Jaeggi et al. (2008) correlated with transfer gains to fluid intelligence tests - allowing the dismissal of concentrated training as a method responsible for a lack of transfer gain. It appears that apparent differences in the execution of dual N-back tasks as WMT may have created the discrepancy in findings.

Chein and Morrison (2010) used a concentrated WMT program (twenty sessions over four weeks) on forty-two YAs to test the malleability of working memory in response to WMT, using verbal and spatial complex working memory span tasks. Against a passive control, the study reported that participants showed improvements in tests of temporary memory, including transfer gains in reading comprehension. Schneiders et al. (2012) also found transfer gains using concentrated adaptive WMT paired with an N-back task. Their study of thirty-two undergraduates using fMRI to record neurological activation found both trained and transfer related gains in neural efficiency, demonstrated by the decrease in activation of two regions of the right inferior frontal gyrus (part of the frontal cortex) during an auditory task. The findings of these studies reinforce the theme of decreased neural activation (an increase in process efficiency) as an effect of WMT. Furthermore, Takeuchi et al. (2011) found trained task and transfer task gains, specifically referring to "practice-related performance" (p.5) increases in tasks requiring similar activation to the WMT tasks (in this case a computer based protocol requiring mental multiplication). This finding suggests not only a decrease in activation and increase in efficiency but that these changes occur in neural structures specifically used to complete the task – therefore creating performance gains in similar tasks that require the same neural structures to be activated.

A significant proportion of the literature on concentrated adaptive WMT involves the use of span tasks. Within this area, all reviewed studies reported increases in trained task and transfer task performance (Loosli et al., 2011, Brehmer et al., 2011; Brehmer et al., 2012; Bastian et al., 2013; von Bastian and Oberauer, 2013) whilst also suggesting that WMT had greater effects on younger populations such as YA and Ch when compared with OA (Loosli et al., 2011, Brehmer et al., 2011; Brehmer et al., 2012; Bastian et al., 2013). Furthermore, support for the findings in Takeuchi et al. (2011) was found in von Bastian and Oberauer (2013). It is these findings that provide a grounding for a WMT principle of specificity.

Bastian et al. (2013) conducted an age-comparative study between YA and OA, intervening by using WMT tasks categorised for each functional category of working memory and testing the effects using near and far transfer tests that included reasoning. Against an active control, the experimental groups showed performance increases in trained tasks (near transfer) and a structurally similar non-trained task. Within this performance improvement, YA showed a greater magnitude of change when compared with OA. Based on these findings, Bastian et al. (2013) contend that working memory performance can be improved with differing magnitudes across the lifespan. Furthermore, the simultaneous training of multiple functional categories of working memory was found to induce fewer transfer effects than the training of singular functional categories. This finding suggests that when using WMT, careful consideration must be taken to ensure the overload of one specific functional category which, based on the work of Takeuchi et al. (2011) and von Bastian and Oberauer (2013), correlates functionally with the transfer task where a performance gain is desired.

Brehmer et al. (2011, 2012) performed two experiments using computerised span tasks for WMT, examining the effectiveness of WMT on OA against an active control, as well as comparing performance changes to those achieved with YA. Once again, it was found that adaptive training created performance gains in tests of trained and non-trained tasks, whilst the magnitude of improvement in YA exceeded that of OA. These findings were supported by Loosli et al. (2011) who found significant improvement in the working memory performance of children after an intervention of only ten days using a novel span task – though it should be noted that this comment was made in reference to trained tasks. The trend gives further weight to the claim that WMT can affect working memory function throughout the lifespan (Bastian et al., 2013) with varying magnitude relative to age. Brehmer (2011) also found decreased frontal brain activity after WMT despite increased performance – once more pointing towards an effect on neural efficiency. Improvement on test scores was found to correlate proportionally to the magnitude of decrease in activation in the frontal brain, also highlighting the potential to improve the performance of non-trained tasks and further supporting the concept of a specificity principle in the field of WMT (Takeuchi et al., 2013). Brehmer et al. (2012) also found that performance effects were retained in tests performed three months after the intervention, a finding that suggests long term development of working memory can be achieved with appropriately prescribed training.

Von Bastian and Oberauer (2013) used a series of span tasks within a concentrated adaptive program, as well as a task-switching exercise found in Karbach and Kray (2009). In a computer-based intervention using YA, the study gave two important conclusions. First, the degree of improvement in a trained task correlated proportionally with the degree of improvement in a related transfer task. Second, training specific processes leads to improvement in transfer task performance in tasks that engage similar processes. In addition, it was found that storage-processing training had an effect on working memory – highlighting the reason behind the wide use of span tasks in the field – as well as reasoning, whilst supervision training had an effect on task shifting (related to executive control) and reasoning. These findings further support the presence of a specificity principle of WMT (Takeuchi et al., 2011). These findings also present the possibility that tasks could be attributed to their relative neural constructs, which could then be matched to particular categories of WMT tasks. This process could present the opportunity for coaches to understand the relevance and training of different constructs and their characteristics (similar to the training of different energy systems in physical conditioning). Such knowledge could be used to build multi-faceted, sport specific, WMT programs that could guide long term development of working memory within an individual.

2.2.3.2 Distributed adaptive training

Distributed adaptive training, training carried out with a frequency of less than three training sessions in a week, correlated with eliciting both trained and transfer tasks gains (Dahlin et al., 2008; Zimmer et al., 2012; Heinzel et al., 2013). No reports were made of trained gains only, although this could be attributed to the smaller volume of studies when compared with concentrated adaptive training. Within the field, trends from other sections of the literature were also apparent; proportionally different training gains in favour of YA when compared with OA (Dahlin et al., 2008; Heinzel et al., 2013); the existence of performance gains in the long term after a WMT intervention (Dahlin et al., 2008); whilst Zimmer et al. (2012) discussed the theory of WMT affecting neural efficiency against capacity theory with further reference to a principle of specificity on WMT.

Heinzel et al. (2013) found training and transfer tasks gains from WMT in an age-comparative study of OA and YA. In a study of 62 participants, who completed twelve sessions of forty-five minutes over a four-week period against a passive control, the YA group were able to reach a mean difficulty level of 12 compared with an OA mean difficulty of level 5. Both groups began at difficulty level 1 and progressed through the levels based on the adaptive WMT algorithm (von Bastian and Oberauer, 2012; Bastian et al., 2013) Both experimental groups showed transfer gain in a digit substitution test. The findings of trained and transfer gains from distributed adaptive WMT, with more significant changes in YA, were also found by Dahlin et al. (2008), who investigated the presence of immediate trained and transfer tasks effects and effect maintenance eighteen months after the intervention – with comparisons between YA and OA. The computer based WMT comprised of fifteen sessions in five weeks, all of which were forty-five minutes in length. The results showed both groups improved their test scores significantly against a passive control, with transfer gains restricted to the YA population and improvements maintained in a subsequent test 18 month after the intervention.

Based on these findings Dahlin et al. (2008) were able to further support the claims of WMT being able to affect brain plasticity and functioning across the lifespan (Loosli et al., 2011; Bastian et al., 2013), with differing magnitudes of improvement observed in favour of younger populations (Loosli et al., 2011; Brehmer et al., 2011; Brehmer et al., 2012; Heinzel et al., 2013). Furthermore, the emerging trend of training effects being maintained long after a WMT intervention (Dahlin et al., 2008; Jolles et al., 2010) further supports the concept of a super compensation principle existing for WMT.

Zimmer et al. (2012) discovered trained and transfer gains in a study involving change detection, using fMRI to analyse neural activation. In addition to this finding, evidence of WMT affecting neural efficiency was noted. This interpretation was made due to a correlation between improved performance and a decrease in activation of the neural structures that support the WM components required to perform the task. Zimmer et al. (2012) also emphasised that despite transfer task gains being present, the magnitude of improvement compared with trained tasks gains is inferior – this is to be expected, however, it is important that this is used to give a realistic grounding to the perceived magnitude of transfer gains. Furthermore, it once again raises issues around a possible principle of specificity for WMT, highlighting the need for executing the correct exercises in environments totally specific to those where a transfer gain is being pursued. Considering this point, the work of Zimmer et al. (2012) also reflects findings through the lens of capacity theory (Just and Carpenter, 1992; Conway, 1996; McCutchen, 1996; Waters and Caplan, 1996), a concept that proposes working memory has a fixed capacity of activation. Zimmer et al. (2012) propose that rather than expand the capacity of working memory, WMT changes the size of activation required for tasks related to the component of working memory being developed. Once more, this suggestion highlights the importance of specificity in WMT.

2.2.4 Adaptive vs non-adaptive training

Within the literature, this review identified only a single study that compared the implications of adaptive and non-adaptive training. It is acknowledged that this is a potential weakness of the review process, however, given the thorough methodology carried out in this review, it is also possible that this is also a weakness of the field itself. Holmes et al. (2009) compared adaptive and non-adaptive training for forty-two children, using non-adaptive training as a control. The study found that adaptive WMT correlated with sizeable gains when compared with the control. Given the algorithm for adjusting the challenge of adaptive training (von Bastian and Oberauer, 2012; Bastian et al., 2013), it is little surprise that this is the case, given that the algorithm is similar to the concepts of balancing challenge and success and/or Flow theory, both relevant in sport coaching literature.

2.2.5 Distributed vs Concentrated WMT

When comparing distributed and concentrated training, Penner et al. (2012) found that distributed training led to increased performance gains. The Penner et al. (2012) study used computerised training on thirty-six adults with two different program frequencies (the study itself uses the word “intensity”, a term that could create ambiguity when used in the Football Coaching context). The first program, concentrated training, entailed forty-five-minute-long sessions, four times per week for four weeks; whilst the second program, distributed training, involved forty-five-minute sessions, twice per week for eight weeks. The results of the research showed that distributed training led to increased performance in all tested domains when compared to concentrated training – demonstrated strongly in tests of verbal and visual working memory, processing speed and verbal short-term memory.

2.2.6 WMT tasks

A total of twenty-two different WMT tasks were used in 21 studies that showed a positive correlation between WMT and transfer gains. 57.14% of these studies used either an N-back or Span task type to conduct their WMT. This provides evidence that these two task types are effective in creating transfer gains if used as WMT, conversely, this also highlights the need to research the remaining tasks further. Further research would also help categorise other WMT tasks, as it is possible that tasks not included within the N-back or Span task categories in this review involve the same neurological processes required from these tasks, and as a result could be wrongly dismissed.

Within the working memory tasks used, an interesting finding was the successful use of novel working memory tasks that were designed based on the structure and function of working memory (Smith et al., 2009; Loosli et al., 2011). Loosli et al. (2011) performed a study on sixty-six Ch to experiment with the effects of WMT on reading tasks. This study used a novel span task based on a similar task used with OA (Buschkuel et al., 2008) that tapped storage and processing resources drawn from span measures including reading, operational and spatial span tasks (Daneman and Carpenter, 1980; Shah and Miyake, 1996; Conway et al., 2005) The study found that the WM improvement by the participants extended to a non-trained reading task that was based on G*f* (fluid intelligence) testing (see Jaeggi et al., 2008).

Smith et al. (2009) found an experimental group of OAs improved general measures of attention and memory to a greater degree than an active control group of OA. The tasks used in this study were computerised, but were based on principles of brain plasticity. It should also be noted that this study involved a training volume of one hour per day, five days per week – which with the knowledge that distributed WMT appears to be more effective than concentrated WMT – meaning that the improvement recorded may have been limited by the training volume prescribed.

These findings suggest that it is possible to create new training tasks that are effective. However, the degree of effectiveness would have to be individually tested for efficacy in affecting working memory and creating transfer task effects. Nonetheless, this is important knowledge that informs the process for any effective shift of WMT into a new context (e.g. Football Coaching). This point also reinforces research relating to a principle of WMT specificity.

2.2.7 Summary: Principles of using WMT

Based on the literature (see table 2.1 on p.57), the following suggestions can be made:

- WMT can be used to create improvement in both trained and transfer tasks.
- Adaptive WMT is more effective in creating trained and transfer-task gains when compared with non-adaptive training.
- Distributed WMT is more effective in creating trained and transfer task gains when compared to concentrated WMT.
- Increased performance in trained and transfer tasks is caused by changes in neural processing efficiency, rather than a change in WM capacity, as a result of WMT.
- To create effective and relevant transfer task gains, WMT tasks must be specific to the processes required for the transfer task.
- WMT can create long term changes in trained and transfer task performance, as a result of changes in neural plasticity and activation.
- All age groups are capable of achieving performance gains through the use of WMT, however, the magnitude of these changes is much larger in Ch and YA compared with OA.
- Span and N-back tasks are effective in creating transfer-task performance gains.
- It is possible to create novel WMT tasks that are effective in creating transfer-task performance gains.

These claims have informed the design of application principles for WMT:

- Principle of WMT Specificity

    - WMT is most effective when used in a task specific manner or in tasks requiring similar processes to the WMT tasks.
- Principle of WMT Frequency
    - WMT is most effective when used with a distributed frequency allowing 48 hours rest between training sessions.
- Principle of WMT Volume
    - WMT is most effective when delivered for a duration between 15 and 45 minutes.
- Principle of WMT Progression
    - WMT task difficulty is most effectively progressed based on the algorithm suggested by Bastian et al. (2013):
        - <50% success – difficulty decreases
        - 50-80% success – difficulty remains constant
        - >80% success – difficulty increases
- Principle of WMT Complexity
    - It is suggested that WMT should not be trained in conjunction with other forms of overload that could influence available working memory capacity – such as physiological overload.

Table 2.1 Summary of WMT literature reviewed

Author	Year	Participants	Training method (AT: Adaptive) (T: Non-adaptive)	WMT tasks used	Training schedule (Concentrated / **Distributed**)	Session duration (mins)	Trained task effect (Y/N)	Transfer task effect (Y/N)	Control (AC: Active Control/ PC: Passive Control)
Bastian et al.	2013	66 YA, 57 OA	AT	numerical complex span, Tower of Fame, Figural task switching	4 weeks, 20 sessions	30	Y	Y	AC
Brehmer et al.	2011	24 OA	AT	span board forward, Digit Span backward, span board backward, Digit Span forward, PASAT, Stroop, RAVLT, RAVEN	5 weeks, 25 sessions	25	Y	Y	AC
Brehmer et al.	2012	55 YA, 45 OA	AT	span board forward, Digit Span backward, span board backward, Digit Span forward, PASAT, Stroop, RAVLT, RAVEN	5 weeks, 20-25 sessions	M=26	Y	Y	AC
Chein and Morrison	2010	42 YA	AT	Verbal Complex Working Memory, Spatial Complex Working Memory	4 weeks, 20 sessions	30-45	Y	Y	PC
Chooi and Thompson	2012	93 YA	AT	Dual N-back	2 OR 5 weeks, 8 OR 20 sessions	30	Y	N	AC and PC
Dahlin et al.	2008	32 YA, 32 OA	AT	Letter memory task (adaptations), keep-track task	5 weeks, 15 sessions	45	Y	Y	PC
Dux et al.	2009	7 YA	T	Single Auditory-Vocal Trials (AudVoc), Single Visual-Manual Trials (VisMan), Dual-Task Trials: AudVoc and VisMan simultaneously	2 weeks, 8-12 sessions	90	Y	Not tested	None
Heinzel et al.	2013	15 YA, 15 OA	AT	N-back	4 weeks, 12 session	45	Y	Y	PC
Holmes et al.	2009	42 Ch	AT and T	Computer game based (CogMed)	5-7 weeks, 20 sessions	35	Y	Y	AC: Non-adaptive training
Jaeggi et al.	2008	70 YA	AT	Dual N-back	2-4 weeks, 8-19 sessions	25	Y	Y	PC
Jaušovec and Jaušovec	2012	30 YA	T	N-back, Memory/sentence construction, Maintenance task	12 weeks, 12 sessions	75-100	Y	Y	AC

Jolles et al.	2010	29 YA	T	Verbal working memory (Crone, 2006),	4 weeks, M=10.5 sessions	25	Y	N	PC
Jolles et al.	2013	23 YA, 9 Ch	T	Verbal working memory (Crone, 2006),	6 weeks, 15-16 sessions	not stated	Tested for neurological adaptation		None
Loosli et al.	2011	66 Ch	AT	novel working memory span task	2 weeks, 10 sessions	20	Y	Y	PC
Oleson and Klingberg (1)	2004	3 YA	AT	visuospatial working memory task, backwards Digit Span, letter span task	5 weeks, session # not noted	35-45	Tested for neurological adaptation		PC
Oleson and Klingberg (2)	2004	8 YA	AT	Grid, Grid Rotation and 3D Grid (Cogmed)	5 weeks, session # not noted	35-46	Tested for neurological adaptation		PC
Penner et al.	2012	36 A	AT	BrainStim (Penner et al. 2006) ... Computerised WMT	4 weeks, 16 sessions vs 8 weeks, 16 sessions	45	Y	Y	PC
Persson and Reuter-Lorenz	2008	48 YA	T	item recognition, N-back (trained tasks) paired associates, item recognition, verb-generation (transfer tasks)	2 weeks, 10 sessions	40	Y	Y	PC
Redick et al.	2013	75 YA	AT	Dual N-back, Visual search	5 weeks, 20 sessions	30-40	Y	N	AC
Schneiders et al.	2012	32 YA	AT	N-back	2 weeks, 8 sessions	50	Y	Y	PC
Smith et al.	2009	487 OA	AT	Plasticity based novel approach	8 weeks, 40 sessions	60	Y	Y	AC
Takeuchi et al.	2013	55 YA	AT	IATWMMC	1 week, 5 sessions	240	Y	Y	AC and PC
von Bastian and Oberauer	2013	137 YA	AT	Complex span tasks (verbal, numerical, figural-spatial), Relational Integration, Task switching (Karbach and Kray, 2009)	4 weeks, 20 sessions	30	Y	Y	AC
Zimmer et al.	2012	12 YA	AT	change detection/visual span task	4 weeks, 12 sessions	not stated	Y	Y	None

Literature search conducted via University of Canterbury Library multisearch – Key words: "working memory training"

Chapter 3:

Conceptualising the integration of WMT into Football Coaching methodology

The previous Chapter explored the relationship between working memory and expert performance in sport, providing a platform from which the practice relevance of this relationship can be understood. This Chapter will provide a conceptualisation of how WMT could be applied in the context of Football Coaching, followed by the explanation of Csikzentmihalyi’s Systemic Creativity and Flow theory as a theoretical framework, used to understand the qualitative research in Study 1. This includes explaining the professional terms that are used within the context of Football Coaching, to ensure clarity in how WMT can be used. The Chapter ends with a section that summarises by presenting the case for the investigation of WMT within Football Coaching.

3.1 The case for investigating WMT as a training method in Football Coaching

It is clear from the literature that the performance of experts in sport can be dependent on several concepts that underpin an “economy of action” and an “economy of attention” (Gabbett and Masters, 2011) making up perceptual-cognitive skill. These include the use of procedural knowledge (Furley and Memmert, 2010), implicit motor learning (Masters, 1992; Masters et al., 2008), Flow (Dietrich, 2004), resistance to Choking (Schmader and Johns, 2003), motor inhibition (Di Russo et al., 2006) and the efficient allocation of attention (Vestberg et al., 2012). The combination of these concepts within the actions of an expert performer appears to be underpinned by the efficient use of a highly capable working memory system.

Recognising that the working memory system is central to expert performance, it is important to understand how environmental factors can be used to help develop the system.

From an environmental perspective, a coaching environment which applies this theory would be defined by the presence of factors that allow an “economy of action” and an “economy of attention” to occur. These include constraints-based pedagogy (Maxwell et al., 2003; O’Connor et al., 2017; O’Connor and Larkin, 2017; O’Connor et al., 2018) and implicit feedback strategies such as analogy learning (Liao and Masters, 2001; Poolton et al., 2006; Lam et al., 2009), in addition to psychological skill training that involves management of the dopamine system (Bijleveld and Veling, 2014). Such an environment provides a basis for athletes performing in a state of Flow, using implicit actions within a balance of top-down cognitive and bottom-up limbic processes (Dietrich, 2003; Dietrich, 2004; Knudsen, 2007). This would provide a platform upon which the domain-specific use and development of an efficient working memory system could take place.

To engage working memory within domain-specific constraints, it appears that the use of dual tasking (Jackson et al, 2006; Gabbett and Masters, 2008; Furley and Memmert, 2010) is appropriate as a method that limits the amount of available working memory that can be used to complete a task (Waldron and Ashby, 2001). However, one of the criticisms of dual tasking is the difficulty in prescribing tasks in a systemised manner within domain-specific constraints (Gabbett and Masters, 2011; Faubert and Sidebottom, 2012), in addition to the problem of simply occupying working memory with a task, as opposed to the more beneficial approach of using a task shown to create a training effect in working memory.

In solving the problem of systemising dual tasking, WMT appears to provide a solution – and furthermore, provides an opportunity to increase the capability of working memory by affecting the neural networks it relies upon (Dux et al., 2009; and Jolles et al., 2013). Individualised and adaptive WMT (Bastian et al., 2013), with appropriate volume and frequency

(Penner et al., 2012) using span tasks (Chein and Morrison, 2010) and N-back tasks (Schneiders et al., 2012) have been shown to create age-dependent long-term changes in task performance throughout the life span (Loosli et al., 2011). These changes are due to adaptations in neural plasticity and activation in structures such as the DLPFC, with fMRI imaging showing decreased activation alongside increased performance, indicating a positive effect on efficiency (Dahlin et al., 2008; Bastian et al, 2013).

Using WMT as a dual task within domain-specific constraints could provide a tool to accelerate the development of expertise, as well as extend the capabilities of existing expertise. It is the intention of this research to explore how to integrate this type of training into Football Coaching effectively.

The next section introduces the methodology of Football Coaching that will be used as a framework for “current practice” in this research.

3.1.2 The Game Training Model as a Football Coaching framework

This section describes how the identified principles of WMT fit into the broader methodology of Football Coaching, based on the Game Training Model. The objective of the Game Training Model (Cross et al., 2013) is to provide an objective, systematic and hierarchical framework for achieving a designed Playing Model or football philosophy within football training. The hierarchical structure of football in the Game Training Model breaks down the complexity of a complete Playing Model several layers; Playing Model, formation, key principles (when attacking, defending and transitioning between attacking and defending), team tasks, player tasks and player actions. This model allows coaches to break down every concept that needs to be trained within a clear frame of reference, allowing each part to be coached with appropriate exercise structure and language:

Figure 3.1 The Playing Model hierarchy of the Game Training Model (Cross et al, 2013, p.42)

This hierarchy provided by Cross et al. (2013) in Figure 3.1 allows coaches to understand, first, the structure of a Playing Model, and second, how the actions of players and the team fit into each part of the Playing Model. This hierarchy is applied to training sessions using “Passing Practice”, “Positioning Game”, “Game Training” and “Training Game” exercises in a logical order, with the appropriate stages in the hierarchy used in each exercise. For example, player actions in the Passing Practice, and player tasks, team tasks and key principles within the Positioning Game and Game Training (Cross et al., 2013).

The Passing Practice occurs as part of a warm up to begin each training session. These exercises are generally unopposed and require players to make actions relevant to the key principle that is the objective of the football training session. The Positioning Game is an extension of the Passing Practice, where an opposition is introduced to make the exercise more game realistic. The Positioning Game is used to develop the required player actions towards the player tasks required to achieve the objective of the football training session. The Game Training is a match realistic exercise that is used to develop the player tasks and team tasks required to achieve the objective of the football training session. The Game Training exercises are situated on the relevant part of the field with realistic opposition and often use constraints to improve specificity. The final exercise, the Training Game, is an observational exercise used to assess learning of the player actions, player tasks and team tasks during the training session and is typically the exercise that closest resembles a real match.

Player actions form the basis from which achieving the training objectives is possible. “Action” in this case refers to any movement a player performs when playing: for example, passing, pressing (Verheijen, 2014), dribbling or accelerating/decelerating (Andersen and Aagaard, 2017). Within the Game Training Model, player actions are defined by the stages of Perception, Decision Making and Execution (per O’Connor and Larkin, 2018), relative to the moment (attacking, defending, transitioning between attacking and defending), key principle, team task and player task.

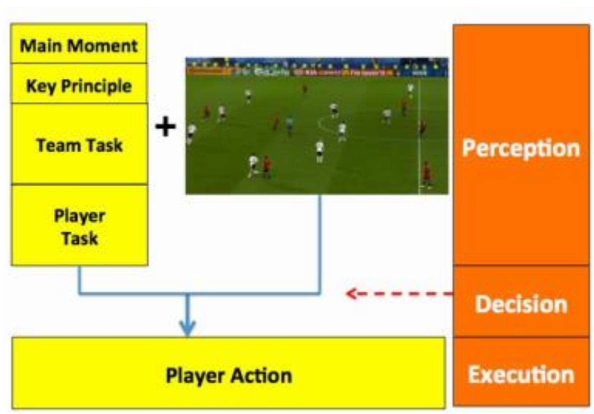


Figure 3.2 The player action model (Cross et al, 2013, p.64)

With reference to WMT, it is these player actions that need to be systematically trained in a Flow environment with an overload using WMT, creating an automisation of the action (fast and stable performance of player actions) whilst making more working memory capacity available during performance to learn more complex variants of the action (based on changes in perception, created by the moment, principle, team task and player tasks). This is explained in the following section, exploring how the principles of WMT identified in Chapter 2 can be applied within the Game Training Model.

3.1.3 Applying WMT within the Game Training Model

WMT requires an individualised and adaptive methodology (Bastian et al, 2013) in combination with task specificity (Takeuchi et al., 2011; von Bastian and Oberauer, 2013). Within the Game Training Model, an individualised and specific approach to WMT can be used by overloading player actions (passing, pressing, dribbling etc.) that occur within the achievement of given player tasks in reference to a team task. The achievement of a team task can be a conscious process, considered as a multidimensional task that uses explicit task rules to guide implicit actions (see Masters, 1992; Maxwell et al., 2003; Gabbett and Masters, 2011). Therefore, it is advantageous to maximise the working memory capacity available for processing and achieving team tasks, meaning that it is important to perform a wide range of implicit player actions with as little working memory activation as possible. The use of WMT during the training of player actions can decrease the amount of activation required by these tasks, whilst also developing working memory structures in preparation for handling more complex tasks later in the coaching process.

As covered in the previous section, player actions and player tasks are achieved during the “Passing Practice”, Positioning Game” and sometimes the Game Training elements of the training session, which culminates in a Training Game” (Cross et al., 2013). Typically, the Game Training occurs from roughly forty-five minutes onwards during a football training session. When compared with the volume principle of WMT (covered in section 2.2.7), this means that WMT should occur within the Passing Practice and Positioning Game elements of the training session.

Beyond the football training session, it is important to note where WMT, based on the principle of WMT frequency, fits within weekly periodisation.

3.1.4 Applying WMT and the Game Training Model within weekly periodisation

As noted by Iaia and Hawkins (2017), a key requirement for success in football is to ensure that players are available for all training sessions and games throughout the competitive season, whilst developing their holistic (physical, technical, tactical and psychological) capability to perform at a level which will help the team win as many matches as possible. This means, firstly, that the training week needs to address the appropriate recovery periods both pre-match and post-match to keep players in injury-free and avoid overloading. Secondly, there must be an opportunity to load players during the week with exercises that will help them win matches in the short term, whilst contributing to long term development of the individual and team. As a result, and as Iaia and Hawkins (2017) and Bangsbo, Mohr and Krustrup (2006) note, weekly planning is therefore dictated, within science-based procedural guidelines, by the number and types of games, the fitness status of players and the characteristics and objectives of the players and team. This planning can be referred to as periodisation (Verheijen, 2014).

A critical part of periodisation each week is the management of post-match recovery in the two days after a match and pre-match tapering in the two days leading to a match to ensure players can perform well in competition (Iaia and Hawkins, 2017). The intermittent work required to perform in football means that during a match, the supply of muscle glycogen (a main source of energy production in muscle fibers) progressively becomes lower, and following the match, can take up to seventy-two hours to be restored to one hundred percent (Andersson, Raastad, Nilsson, Paulsen, Oslash and Ran, 2008) with only a fifty percent restoration after two days (Bangsbo et al., 2006). This means that the highest intensity training during the week can only occur after this seventy-two-hour period as the higher intensity is more likely to be achievable with higher stores of muscle glycogen (Bangsbo et al., 2006). Therefore, during the two days following a match (referred to as G+1 and G+2 – Iaia and Hawkins, 2017), players are generally given a rest day and a recovery training session in order to allow the restoration of muscle glycogen (amongst other holistic factors of recovery) and prepare the body for making intense actions on the third day after the match (G+3) and the training that occurs three days before the match (G-3).

Once full recovery from the match has been achieved, the next objective of the training week is to provide a training stimulus that develops and maximises the physical, tactical, technical and psychological characteristics that players require to perform on match day (Iaia and Hawkins, 2017). This training is designed based on the qualities that players require during the most intense periods of the match and are executed at maximum quality with carefully prescribed volume (Mohr, Krustrup and Bangsbo, 2003; Iaia, and Hawkins, 2017). The training session on G+3 is generally a tactical session that prepares the following day (G-3), where a football conditioning session will take place and high-quality actions will be demanded. This way of training ensures that the player's characteristics, such as muscle composition and work patterns, will be adapted to the needs of the Playing Model during the most intense periods of the match.

Following the training stimulus on G+3 and G-3, a tapering process must occur in the days leading up to the match (G-2 and G-1) to ensure that full recovery and preparation are achieved in time for the match (Iaia and Hawkins, 2017). This achieved by reducing the volume of training and focusing on the specific requirements for the match. G-2 is generally a tactical session with similar loading to the tactical session that takes place on G+3, allowing for supercompensation (positive physiological, technical or psychological changes that occur following a training or stress stimulus – Gambetta, 2007) from the football conditioning session on G-3 to take place. G-1 is also delivered with a reduced volume, but in general, individual specific exercises that focus on explosiveness are introduced in preparation for the explosive actions that are required on match day (Bansgbo et al., 2006). This is designed to train the actions required whilst minimising the use of muscle glycogen in the lead up to the match – ensuring that players are both prepared and rested for the match day.

This weekly process can be repeated within cycles of six weeks (Verheijen, 2014), where the training stimulus that occurs on G-3 is adjusted to target different energy systems required for competition, whilst allowing for tapering, recovery and maintenance of other characteristics. This means that both short term objectives and the long-term development of the player are managed within one model. It is also possible that the workload of each training day is different for each player, based on the monitoring of load during the match and training week (Iaia and Hawkins, 2017). This is often managed by monitoring athlete training load through recording the rate of perceived exertion (RPE) or using a Global Position System (GPS) (Hill-Haas, Roswell. Dawson and Coutts, 2009; Dellal et al., 2011) for each player and adjusting the training week on an individual basis. Adjusting the training week for each individual means that it is possible for players within the same team to be working through differing types of session simultaneously (Iaia and Hawkins, 2017) – for example, a player with high fatigue completing a tactical session as a recovery session, by having their volume of training reduced relative to other players with lower fatigue. The outcome of this whole process of periodisation within the Game Training Model is a fit and rested group of players that are individually adapted to the physical, technical, tactical and psychological needs of the Playing Model.

Figure 3.3 on the following page demonstrates the weekly session structure within a six-week block. The days of the week are oriented based on the day of the Match, followed by G+1, G+2, G+3, G-3, G-2 and G-1. The session types are abbreviated as OFF (day off – G+1 or G+2), REC (recovery session - G+1 or G+2), TT (tactical training – G+3 and G-2), FCT (football conditioning training – G-3) and TTA (tactical training *activation* – G-1, referring to the introduction of individualised explosive exercises within the tactical training – per Bangsbo et al., 2006).

Day	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6
G+1	REC	REC	REC	REC	REC	REC
G+2	OFF	OFF	OFF	OFF	OFF	OFF
G+3	TT	TT	TT	TT	TT	TT
G-3	FCT	FCT	FCT	FCT	FCT	FCT
G-2	TT	TT	TT	TT	TT	TT
G-1	TTA	TTA	TTA	TTA	TTA	TTA
G	Match	Match	Match	Match	Match	Match

Figure 3.3 A Six-week cycle of football periodisation with one match each week, including training sessions types and opportunities for WMT to be used within the team training (red) or based on individual work load (blue).

Based on the performance needs of football, where maximal recovery from all training during the week is required by match day, and the need for distributed WMT without training in overload of other elements, (see section 2.2.7.) it seems that WMT should occur during TT (Tactical Training) sessions on G+3 and G-2, highlighted in red in Fig 3.3. As covered in section 2.2.7, distributed WMT has been shown as more effective in creating performance gains, with a forty-eight-hour recovery period being apparent (Dahlin et al., 2008; Zimmer et al., 2012; Heinzel et al., 2013), therefore if a player is involved in a match the last opportunity to use WMT in preparation for the match is on G-2, leaving enough time for the player to be totally recovered from the WMT. However, use of WMT in TTA (Tactical Training Activation) and REC (Recovery Training) on G+1 and G-1 respectively, could be recommended in individual cases where a player is, based on load monitoring, completing a different training week to his peers or is not involved in a match (Iaia and Hawkins, 2017), highlighted in blue in Fig 3.3.

3.1.5 Integrating WMT into the Game Training Model and periodisation – A summary

If systemised WMT is feasible and beneficial to the Football Coaching process, as a dual task methodology delivered within constraints-based learning exercises, then it is important to understand how the methodology needs to be adapted to fit within the context of Football Coaching. The context presented here is the Game Training Model (Cross et al., 2013; O'Connor and Larkin, 2018), a model that focuses on the development of a Playing Model through a hierarchy of principles and tasks that are coached using a logical progression of contextually specific exercises, developing actions and tasks that are needed to execute a Playing Model. This could enable WMT to be used in the first forty-five minutes of these training sessions during the Passing Practice and Positioning Games to overload and develop player actions and tasks - allowing team tasks and key principles to be addressed as explicit rules within a multidimensional task (Maxwell et al., 2003; Gabbett and Masters, 2011) with the use greater available working memory capacity – therefore creating the opportunity to handle progressively complex tasks with directed attention (per Dietrich, 2003).

Outside of each training session, it is important to consider how WMT can be used as a long-term process within a periodised program of football. Based on a six-week cycle (Verheijen, 2014) with one match each week, whilst taking into account recovery and tapering strategies (Bangsbo et al., 2006; Iaia and Hawkins, 2017) and the need for distributed WMT (Dahlin et al., 2008; Zimmer et al., 2012; Heinzel et al., 2013), WMT could be used during Tactical Training (TT) sessions on G+3 and G-2 each training week. In individual cases, based on load monitoring (Hill-Haas et al., 2009; Dellal et al., 2011) or team selection (Iaia and Hawkins, 2017), the training week may be individualized with different work volumes occurring on certain days for certain players. In these individual cases, it may as be possible that WMT could be used during Recovery (REC) or Tactical Training Activation (TTA) sessions on G+1/2 and/or G-1.

Previously in Chapter 2, the effective use of individualized and adaptive WMT was explored to discuss the relevance and most effective delivery of WMT and tasks to create long term gains in performance. By applying the WMT principles of Specificity, Frequency, Volume, Progression and Complexity to the periodised structure of the Game Training Model, whilst taking into account implicit learning and Flow theory, it is apparent how WMT could be applied as part of a long-term strategy to develop the efficient use of working memory within the context of a Playing Model, creating teams with increased chances of success.

This outcome is underpinned by the correct execution of WMT within each training session. The following section outlines in detail how WMT could be applied within an individual training session.

3.2 Applying WMT within a training session – considerations based on the literature

Section 3.1 demonstrated the theoretical integration of the principles of WMT into the coaching context of the Game Training Model and periodisation. This section follows by briefly covering how WMT differs from previous attempts at dual task training in sport, including differences in working memory processing and potential implications on the practical delivery of training sessions.

3.2.1 Using WMT to improve the efficiency of actions

The efficiency of an action ("economy of action" and "economy of attention" - Gabbett and Masters, 2011) has been described in section 3.1 by the magnitude of working memory activation used to execute an action. As discussed in Chapter 2, using a dual task deliberately limits the amount of activation that can be used to complete an action (Furley and Memmert, 2010; Furley and Wood, 2016; Buszard and Masters, 2017) – therefore training higher efficiency of action. However, dual tasking has only been used to *occupy* working memory (Jackson et al., 2006), whereas the use of WMT can allow us to simultaneously improve the capability of working memory by affecting the plasticity of its neural infrastructure (Dahlin et al., 2008; Smith et al., 2009). With the correct progression and periodisation using the principles of WMT presented in Chapter 2, it may be possible to systematically increase the efficiency of these actions and the capability of working memory by using WMT in Football Coaching with a Flow-based environment as a foundation.

The challenge is that while there are existing methodologies (e.g. psychological skills training) for supporting the creation of Flow state within football, there isn't currently a methodology for using WMT as a dual task within Football Coaching. As noted by Faubert and Sidebottom (2012), the use of lab-based training removes the sporting specificity of actions, whilst attempts to apply dual task methodologies have been limited by poor buy-in from athletes and coaches. Accompanied by the ineffective verbal application of dual tasking by coaches within team sports (Gabbett and Masters, 2011), where hearing the task correctly can be more of a problem than completing the task correctly, dual tasking doesn't appear to be widely accepted as an effective method of training outside of the lab.

By using Span and N-back tasks, which have been shown to increase working memory performance (see section 2.2) it may be possible to not only occupy working memory to increase action efficiency but also develop working memory as a structure. It can be hypothesised that working memory function and skill performance could be developed concurrently, leading to accelerated learning of actions, the adaptation of actions to novel situations and improved automatised performance of actions. This hypothesis can only be truly tested with longitudinal and experimental methods in Football Coaching, *once* we have developed an effective method for integrating WMT into Football Coaching as a dual task.

3.2.4 Investigating how WMT can be used in coaching – introducing a theoretical framework for qualitative research.

As an alternative to dual task training - where working memory is only occupied during an action - WMT presents a method that can be used to both occupy and develop the capability of working memory during specific tasks. It is clear from previous dual task studies that there are outstanding issues of specificity (inappropriate use of lab-based methods), coach and athlete buy in, and effective practical delivery (Gabbett and Masters, 2011; Faubert and Sidebottom, 2012). These need to be solved for WMT to be delivered effectively in training sessions and integrated into the Game Training Model of Football Coaching for long term performance effects. Therefore, the following Chapters describe the investigation of the perceptions and application methods that need to be addressed to develop an effective method for using WMT in Football Coaching. To understand these perceptions and methods, a theoretical framework is required for us to interpret WMT in action and develop effective methods for applying WMT. The following section is a philosophical piece of work explaining how Csikzentmihalyi’s (1996) Systemic Creativity and Flow Theory can be applied as a theoretical framework to understand observations made during Study 1, within which the direct application of the theoretical framework also described.

3.3 Csikzentmihalyi's Systemic Creativity and Flow: A theoretical framework for understanding action

The methodology that follows this Chapter uses the literature review in Chapter 2, and section 3.1 on the conceptualisation of using of WMT in Football Coaching to understand action through the language of perceptual-cognitive skill and working memory. As a broader theoretical framework, Systemic Creativity and Flow theory (Csikzentmihalyi, 1996) is appropriate, as it describes the qualities of interaction with the world through performance, accounting for the balance between cognitive and limbic systems, activation of different neural structures, use of implicit skills, perception, feedback and finally, utilisation of working memory. Within the Flow theory of Csikzentmihalyi (1996) we can view and deconstruct action, described by Csikzentmihalyi as creativity, through an understanding of working memory and perceptual-cognitive skill. However, there does need to be a distinction between the context of Flow in performance and Flow as a system by which to contextualise action in reference to Systemic Creativity. Flow in performance is described in Chapter 2 of this work, referring to expert performance, whilst this section is a philosophical piece of work creating a framework by which action can be contextualised and understood. The latter provides a way of understanding the research environment described in Chapters 4 and 5. Therefore, this section, plus Chapters 4 and 5, refer to and use Flow from a Systemic Creativity perspective to understand the context of action, rather than using Flow in the context of perceptual-cognitive skill.

Csikzentmihalyi (1996) looks at the novel actions of human kind as a creativity process, described as the interactions between a person's thoughts and socio-cultural context. This systemic process, developed through evolution, is the result of a societal need to develop new ways of interacting with the world for survival. Creativity is noted as not being individual, as social evaluation is how an idea is considered valuable, and therefore creative. In a sporting context, it can therefore be constructed that the interaction of an athlete with the environment through decision making is a creative process, and furthermore, it can be argued that the judgement of whether their decision making is valuable is dependent on how the actions fit into the context and objectives of the team and/or competition – mirroring the social evaluation of creativity.

3.3.1 The systemic view of creativity

The social evaluation of creativity raises the potential for a conflict between the individual perception of value in action, versus the societal perception – opening the question of who is right, should an idea be accepted or denied. In sporting terms, this question could be asked of the individual or the team, or with a wider perspective, the team or the community that supports it. The two perspectives in this question raise two opposing issues. Should the individual's perception of usefulness be more valuable, then there is a danger that all creativity becomes subjective and relies on the "assurance of the creator". Conversely, by judging solely upon social confirmation, creativity hinges on the perception of external expertise. Therefore, creativity, our way of interacting with the world, should be seen through a mix of both social and individual lenses. This relationship means that creativity becomes a systemic process.

Csikzentmihalyi (1996) describes this system as a model comprising of three main parts:

- Domain; consisting of symbolic rules and procedures that surround a concept by definition.
- Field; the socio-cultural context of a concept, i.e. individuals who act as gatekeepers.

- Person; the individual who creates a way of interacting with a concept.

Based on these three parts, creativity can be defined as an action carried out by a person that uses the defined rules of a domain and needs to be selected by the relevant field to be included as a new concept within the domain itself. Therefore, creative actions can be understood as those that change or transform a domain, whilst a creative individual would be the person that causes this process.

It needs to be emphasised that within this system all three parts are totally interrelated – the domain and field must be suited to recognising and using novel actions. The person who creates these actions must be able to internalise this system to repeatedly create novel and valid actions, as this system makes their creative actions possible. This concept of internalisation can be very simple – for example the predisposition of a person towards kinesthetic learning and sense of touch. Alternatively, internalisation could occur as an educational and adaptation process through exposure to learning environments and feedback. A combination of these processes in differing proportions (based on the person) is logical for learning to take place.

3.3.2 Entropy as an alternative need to creativity

In contrast to creativity, the need for us to interact with the world in new and novel ways, entropy refers to our need to be comfortable and safe. This concept explains the choice of a person to *not* be creative, to exist within a domain and field without disruption in a comfortable space, put simply, our need to relax. Without this process, a person would simply continue to be creative without any mechanism of sustaining actions, leading to death. As much as creativity is an evolutionary process that has been needed for advancement, entropy is the process that has made this advancement sustainable. Neither disposition can be viewed as good or bad, as neither is possible without the other, they are simply both necessities by which we are enabled to interact, and most importantly, find Flow and enjoyment in action.

It is possible for individuals in the same domain and field to find enjoyment in their interaction, or to not find enjoyment in their interaction. Assuming the domain and field remain constant, the variable that affects enjoyment cannot be *what* someone is doing, but *how* they are doing it. This relationship explains why person A could enjoy creativity within a domain and field whilst person B could enjoy entropy in the same domain and field. Conversely, if the same individuals were forced into a position where they had to do the opposite, person A acting through entropy and person B acting through creativity, then those individuals would not be finding the same enjoyment within the domain and field.

3.3.3 Environmental qualities that allow creativity through Flow

According to Csikzentmihayli, even the most abstract of minds are affected by their surroundings, the difference with creative individuals, however, is that they can disregard external surroundings and still perform the same actions. Therefore, when we discuss the environment, it cannot be in reference to the physical surroundings of an individual, but rather, with reference to the systemic view of creativity, a reference to the domain and field in which a person is situated. An individual with a clear connection to their domain and field will be able to recreate the right environment through routine and subsequently find the rhythm and habits of their Flow state, regardless of external factors that are relevant to the domain and field. Therefore, the environmental qualities that facilitate Flow experience may not be constructed by the physical environment around us, but the perceptual/experiential environment that is constructed and experienced within the mind of the creative person.

This connection, of course, takes time to master and in the early stages of development may rely on the external presence of domain and field relevant factors; for example, interaction with individuals who consistently socially validate the actions of the creative person, leading to increased excitement and “effervescence” of ideas.

3.3.4 Creating environments for Flow experience

If the environmental qualities for Flow can be constructed within the mind of the individual, then it is advantageous to know how these qualities can be constructed deliberately with repetition. It is noted that stimulating or novel surroundings *encourage* new ideas and perspectives on action and can provide a convenient foil for recreating the environmental qualities for Flow – the key is to match the surroundings with a prepared mind that can recreate the ideal environment for Flow to take place. Again, this process is made possible by the environment constructed in the mind first, with external influences a factor that will either make Flow more difficult or less difficult to achieve.

When interviewing people who described their Flow experiences, Csikzentmihalyi found that the most creative experiences occurred during activities such as walking or driving – activities that are completed with a certain magnitude of automation but still require some activation in the cognitive system and working memory. This means that both the limbic and cognitive systems are in use, and due to the use of some activation in the cognitive system, it is possible that the top-down and bottom-up signals are balanced (per Dietrich, 2003; Dietrich, 2004; Knudsen, 2007). This balance makes a Flow state possible, not allowing too many conscious processes to occur, whilst not acting purely on a survival or subconscious basis – especially important when considering symbolic activities such as art, dance or sport in contrast to survival actions such as hunting. As Csikzentmihalyi emphasised, giving full attention to a complex problem is not always the best method for creating novel solutions. It can therefore be argued that these “semi-automatic” activities give us a foundation from which we can build a state of in-the moment presence to induce a Flow state. Participation in a sporting situation of the right challenge level can provide this foundation – like the focus on breathing awareness used in meditative techniques, both can act as an anchor of attention that allows bottom-up signals from the subconscious to present themselves.

3.3.5 Enjoyment from action: Flow

With *how* action is done presented as a defining factor for enjoyment taking place, Csikzentmihayli investigated the perceptions of this enjoyment and when it took place. The research reported (in general) a feeling that was not present when taking drugs, consuming alcohol, or other perceived indulgences. This feeling occurred during potentially risky activities that also presented elements of novelty, a feeling that was later referred to as “Flow”. Flow was described as a quality of automaticity and effortlessness in action, occurring as a highly-focused state of consciousness, and was reported almost identically across many different activities, regardless of age or gender, as a “most rewarding” experience.

Csikzentmihayli developed his research to determine Flow as a state involving nine main elements, detailed earlier in Chapter 2. For reference here:

1. Clear goals at each step
2. Immediate feedback to action
3. A balance of challenge and skill
4. Merged action and awareness
5. Exclusion of distractions from consciousness

6. No fear of failure
7. Distortion of time perception
8. Lack of self-consciousness
9. The activity becomes autotelic (self-fulfilling).

These nine elements describe the qualities of concepts such as implicit skill (Masters, 1992; Maxwell et al., 2003; Masters et al., 2008; Furley and Memmert, 2010), constraint-based learning (Masters et al., 2008; Williams et al., 2011; O’Connor et al., 2017; O’Connor et al., 2018), the efficient use of working memory activation (Ward et al., 2003; Mann et al., 2007; Voss et al., 2009; Vestberg et al., 2012*;* Verburgh et al., 2014) and the balancing of cognitive and limbic activity (top-down and bottom-up processes respectively – Dietrich, 2003; Dietrich, 2004; Knudsen, 2007). This is due to the emphasis on perceived automacity, the balance of challenge and success, and the decreased consciousness involved in performance.

The most relevant examples of the link between the characteristics of Flow and the application of implicit skill within constraints can be found in individual sports that have immediate life/death consequences. For example, the snowboarder who must constantly perceive the safest line to descend a mountain, but in doing so, navigates that line whilst never considering the technical details of how he/she turns, accelerates or decelerates, all of which are performed with large degrees of implicitness. As the constraints of a mountain are constantly changing throughout the descent (steepness, rock features, ice, powder), there has to be a merge between action and awareness that allows the snowboarder to plan action and perform action simultaneously. The final link in this example would be the immediate feedback that comes with the consequences involved if a descent goes wrong. The difficulty of the descent (i.e. the constraints) need to be appropriate to the level of the snowboarder to avoid an anxiety response strong enough to overload working memory, preventing merged action and awareness taking place due to lack of resource. Therefore, for the snowboarder performing in Flow, there needs to be appropriate constraints, a large degree of implicit skill and a balance of top-down and bottom-up signals that do not overload working memory during action. It should be noted, per section 3.3.3, that the perceptual/experiential environment can be influenced, indicating that the same degree of challenge could be reframed by an athlete in a manner that mediates pressure or fear. In sum, a Flow environment needs to allow, without interference (fear, time pressure, the quantity of tasks), a constant perceptual-cognitive feedback loop between action and awareness in response to changing constraints with a consistent difficulty.

In relation to the evolutionary discourse on the experiences of creativity and entropy, the elements of Flow and the activities where Flow can occur show a shift towards “non-instinctive” actions (i.e. not essential for survival) that are complex and symbolic in nature. This shift is in line with the social development of human civilisation, now at a point where many actions previously needed for survival are not needed. This shift is therefore the result of an environmental change.

3.3.5.1 A systemic view of the Flow environment

To fully understand the structure of the Flow environment, Csikzentmihalyi used a systemic view to understand the factors that can affect a person within the creative system of domain, field and person. The systemic view of creativity and Flow is split into two parts – the macro system and the micro system, but a third part of the system can be used to help describe actions in sport. As a result, there is a change in nomenclature within this section to explain the system fully, with the Macrosystem becoming the mesosystem and the microsystem becoming the Macrosystem, allowing for a different account of the microsystem:

- Mesosystem; the sociocultural setting within which lies the creativity components of domain, field and person – determining what forms of creativity can take place.
- Macrosystem; the specific and immediate environment that exists as a result of the Mesosystem, for example, a football training session, determining the conditions (e.g. challenge vs skill) that increase or decrease the probability of Flow being achieved in creative actions.
- Microsystem; the experiential and perceptual process undertaken by the individual within the Macrosystem, for example, the decision making of a football player who is passing the ball to a team mate.

This change in nomenclature is based on Csikzentmihalyi's account of Flow being determined most by the experiential environment built within the mind of the creative person. This view of Flow means that there are two potential avenues in determining a process for Flow state. The first avenue involves the Microsystem being totally determined by the systems above, and therefore making Flow a matter of probability, and subsequently meaning that different Mesosystems or Macrosystems could have a "Flow advantage" versus other systems. This would make the actions of the individual simply a product of a top-down system. In contrast, we can take a bottom-up view of the system, where the careful construction of the Microsystem can be used to determine how the Macrosystem and Mesosystem are perceived, and subsequently change or filter characteristics that help or hinder Flow. For example, goal setting can be used to increase the challenge in a football training exercise without any environmental factors (such as the opposition) being changed – thus addressing inefficiencies in balancing challenge with skill to facilitate Flow.

As Csikzentmihalyi points out, no individual can do a great deal about what is objectively happening in the Mesosystem, however, we can control what characteristics we allow to affect us. To achieve a repeatable process for achieving Flow we must construct our own perceptual and experiential environment through the creation of habits that directly control the facilitation of Flow. Csikzentmihalyi explained this using the example of a home owner using decorations or objects as meaningful symbols to reinforce their routine or identity – this example can also be seen through the use of artefacts and rituals in the building of effective organisational culture (May, 2001).

Largely, this returns to creating an environment where the individual feels in control, comfortable and without distraction – whilst building extra processes for dealing with situations that compromise attention or comfort to a degree greater than generally experienced. In fact, such unusual disruptions to the Macrosystem, but dealt with using a clear process, allow us to discover effective novel ways of interacting with the world.

3.3.6 Summarising Flow as a Theoretical Framework

Flow theory can be used as a framework to understand the environment that can determine how and why actions occur. Csikzentmihalyi's work posits action as the creative process of a person interacting with the world, balanced with entropy (non-action) and occurring with the three-part creativity system of the person, field (socio-cultural context) and domain (objective conditions). Flow itself is described as a state involving automacity and effortlessness in action, related to a highly focused and balanced state of consciousness and described by nine elements. The nine elements of Flow link closely to concepts presented earlier in this research, such as implicit skill (Masters, 1992; Maxwell et al., 2003; Masters et al., 2008; Furley and Memmert, 2010), constraints-based learning (Masters et al., 2008; Williams et al., 2011;

O'Connor et al., 2017; O'Connor et al., 2018), the efficient use of working memory activation (Ward et al., 2003; Mann et al., 2007; Voss et al., 2009; Vestberg et al., 2012; Verburgh et al., 2014) and the balancing of cognitive and limbic activity (top-down and bottom-up processes respectively – Dietrich, 2003; Dietrich, 2004; Knudsen, 2007). The environmental qualities that affect Flow are described systemically using a hierarchy of systems to describe immediate actions, the context they can occur within and the socio-cultural system that affects the context. Csikzentmihalyi's work suggests the chances of Flow could increase or decrease based on differences in this system, however, the critical point is that perception and the experiential environment constructed within the mind of the person (the Microsystem) is the most determining factor in creating Flow experience. The characteristics of Systemic Creativity and Flow Csikzentmihalyi's work to be used as a theoretical framework through which we can view, describe and investigate action. In the context of Study 1, allowing the perceptions and experiences of players, coach and researcher in using WMT within the context of Football Coaching to be investigated.

3.4 Chapter 3 summary – understanding the application of WMT to Football Coaching

The principles of WMT identified in Chapter 2 can be applied within the Game Training Model (Cross et al., 2013) whilst still adhering to the contextual needs of developing a Playing Model (Cross et al., 2013), managing the work load of players (Hill-Haas et al., 2009; Dellal et al., 2011) and the individualization of training (Bangsbo et al., 2003; Iaia and Hawkins, 2017). This could help create success in competition and improve individual performance by developing the ability of players to compete with greater available working memory capacity. From a theoretical perspective, it appears that it could be possible to use WMT within the coaching context, however, this is dependent on the correct application of WMT within each training session – which to date, has not been investigated.

The use of WMT within a training session can be understood by using Systemic Creativity and Flow as a theoretical framework to understand action. According to Csikzentmihalyi (1996), Flow systemically describes the most enjoyable and high performing forms of action, whilst Systemic Creativity describes the objective conditions and socio-cultural context within which action can take place. The elements of Flow link to known indicators of perceptual-cognitive skill. These links allow the understanding of the underlying processes of action. Therefore, Systemic Creativity and Flow provide an external and internal systematic lens through which action can be understood.

An objective of this research is to find a method for applying WMT in within Football Coaching and investigate its impact, beginning with situating and investigating WMT within the coaching context. This research will form the basis from which the effects of WMT within Football Coaching can be explored and further understood. The following Chapter describes the methodology that was used in Study 1.

Chapter 4: Methodology

Chapter 3 presented the conceptualisation of applying WMT within Football Coaching, as well as outlining the theoretical framework within which the actions performed in a Football Coaching session can be understood. This Chapter will describe how and why the use of WMT in Football Coaching was investigated as a PAR study, first providing background on the origins of PAR itself, followed by background on the use of PAR in sports coaching research. Finally, the Chapter will describe the exact PAR process used for this research, including the research design, methods and ethical considerations that shaped the research.

4.1 The need for a socio-cultural approach for applying WMT in Football Coaching

A lack of effective on-pitch application methods for dual tasking and perceptual-cognitive training in sport coaching has been described within the literature, with two issues being apparent; (1) a lack of coach buy-in to the potential performance benefits and methods application, and (2), a lack of athlete buy-in to performing the training (Faubert and Sidebottom, 2012). In both issues, the lack of buy in has been suggested as being due to impractical integration into coaching delivery, for example, counting up or down in 2’s from a changing start point during a football exercise (Gabbett and Masters, 2011). The use of these impractical methods has been further compounded using non-specific football exercises to make dual task methods possible to apply, thereby compromising the football element of the training by removing the reference to a Playing Model. Another example of this issue is the use of lab-based cognitive training where there is no sports element (Faubert and Sidebottom, 2012). This use of abstract tasks, delivered in an impractical manner, has made it difficult for coaches and athletes to understand the purpose of the training and therefore affected their buy-in to the methods.

Furthermore, it can be questioned whether dual-tasking without WMT is the most efficient use of a dual-tasking methodology.

At this point it is important to apply the theoretical framework of Systemic Creativity and Flow, described in Chapter 3, to understand the problem in a systematic way using the three terms of *domain* (symbolic rules and procedures), *field* (the demographic within a domain that provide social acceptance or rejection of ideas) and the *person* (the individual who engages in novel actions). From the creativity perspective of Csikzentmihalyi (1996), the issues of coach and athlete buy-in to new methodology can be understood as a social rejection of novel actions by the *field*, the *field* consisting of both coach and athlete. This rejection can be solved by removing the perceived threat of novel methods by giving the coach and athlete (*field)* power in assessing how novel methods, in this case WMT, can be combined with existing methods to create new practice. This process relies on two factors. Firstly, legitimizing WMT as a possible training tool by understanding its potential benefits for participants (from a training experience perspective) and benefits for coaches (through clear training principles). Secondly, the coach and athlete need to be given the opportunity to assess how WMT methods fit into current practice and have a voice in how this is achieved.

To allow the coach and athlete to have an influence on the addition of WMT to existing methods, it is necessary to create a collaborative relationship between coaches, athletes and researchers, using careful and systematic interaction to create an outcome that advances the profession. By using collaboration, it is possible to create an environment where coaches and athletes are actively involved in the development of WMT, removing conversational barriers between theory and practice to address issues in athlete and coach buy-in. An example of this concept can also be found in education, where action research is widely used to encourage collaborative professional development and the application of new research into practice, as demonstrated in Hine (2013), who discussed how action research functioned as a facilitative tool in improving the professional development of teachers. The following section gives a background on the form of action research methodology (PAR) that will be used in this study

4.2 PAR: An overview

This study aims to investigate the application of WMT into Football Coaching. The process of this integration includes three participatory groups - athlete, coach and researcher. To investigate the methods being trialed, all three participatory groups will be engaged in a collaborative research process that offers the opportunity to change and test new practice. A PAR methodology is situated within the paradigm of critical theory (Kemmis, 2008) and draws upon a constructivist framework (Baum, 2006), underpinned by collaboration (Winter and Munn-Giddings, 2001) co-learning (Schurman, 1996) and democracy (Bargal, 2006).

Kemmis (2010) describes PAR as an exploration of the “happening-ness” of action and practice through application and change. PAR models a democratic relationship between all participants so that an unforced consensus on practice can be achieved. Drawn from the work of Hadot (1995), who describes a “philosophical life” as one of logic, avoiding harm and relating to others, PAR seeks to help to find less unsustainable and effective ways of living in the world (Kemmis, 2010) by generating knowledge through co-perceived experience.

PAR is an approach that first seeks to understand, and subsequently, seeks for action to create change (Khan, Bawani and Aziz, 2013). By seeking to understand and improve contexts through change, PAR presents itself as both a collective and self-reflective inquiry (Baum, MacDougall and Smith, 2006) that allows knowledge to be co-constructed as a response to the objective conditions of action. Therefore, PAR has an emphasis on creating (for participants involved in the research) a public forum for public discourse (Kemmis and McTaggart, 2006).

The framework of PAR is reliant on human perception and experience as the basis by which experience is gained. The use of PAR allows a context to be explored through triangulation of perspective, in a Deweyan sense, exploring and creating experience in a way that creates the opportunity to redesign the objective conditions within which experience (practice) takes place. As Kemmis (2010) comments, PAR changes patterns of ‘saying”, “doing” and “relating” to form new patterns and ways of living.

4.2.1 Using PAR methodology

The practice of reflective inquiry used within PAR is cyclical (Baum et al., 2006) described by Bargal (2006) as a spiraling process of data collection that determines, implements and assesses action repeatedly to affect practice. This process is referred to as a spiral, as even though the structure of action research cycles is constant, the details of each cycle change in response to the last cycle, therefore moving the research in a continuing direction. PAR pays attention to power relationships (Baum et al, 2006) by managing trust and respect through placing the participants in a position of influence similar to that of the researcher. The management of power relationships is achieved by using methods that allow participant views to be considered alongside the views of the researcher, as stakeholders involved in a democratic process. Examples of these methods are participant interviews and focus groups. Therefore, the creation of knowledge becomes collaborative, allowing the development of action to happen as a response to the perceived experience of all participants - as Schurman (1996) surmises, the balance between research and intervention.

In the context of this study, PAR allows the integration of WMT into Football Coaching to take place using the objective conditions of the coach and player environment as a starting point. As Lewin suggests (as cited by Bargal, 2006), action research is a problem-solving process that exists in environments that undergo frequent change – such as the environment faced by coaches and athletes.

The cyclical process of PAR involves three steps, which are referred to with varying terminology in the literature, but all involve similar actions which can be described using the terms data collection, reflection and action. The data collected is triangulated to enable the comparison of each perspective of the action taking place. Sources for triangulation include video, participant interviews and field notes – and the methodology allows for novel methods of data collection based on the context of the research (Bargal, 2006).

Andrew, Carol and Patience (2013) reported the use of interviews (individual participants), focus groups (participant groups) and observation (researcher field notes) in exploring the use of stress interventions in the workplace – subsequently finding that these methods addressed issues of stakeholder engagement and ensured appropriate reflective processes. In a similar design that addressed female empowerment in Muslim cultures, Khan et al. (2013) concluded that the PAR process protected the rights of the participants to benefit from the research, by accommodating questions and concerns of the research participants during each research cycle. Within the same study, Khan et al. (2013) argued the case for PAR from an ethical point of view, on the basis that the legitimacy of research should be based on its immediate relevance to the objective conditions of life.

In summary, PAR provides a means by which collaboration (Winter and Munn-Giddings, 2001), co-learning (Schurman, 1996) and democracy (Bargal, 2006) can be operationalized to investigate the use of new pedagogical methods, whilst also addressing the power relationships and barriers between researchers, practitioners and participants (Baum et al., 2006). The application of PAR is a spiral (Bargal, 2006) involving cycles of data collection, reflection and planning (Bargal, 2006; Baum et al., 2006; Kemmis, 2006; Andrew et al., 2013; Khan et al., 2013) that constantly evolve based on the findings of each cycle. The data within each cycle is triangulated (Bargal, 2006) and can be collected from various sources such as interviews, focus groups and observation (Andrew et al., 2013).

The following section details how action research has been previously used in sports coaching, leading into a subsection that provides specific examples. Like this research, these example studies used PAR to integrate new practice into existing practice. The studies were conducted through a paradigm of critical theory, within which action research can be situated (Kemmis, 2008), including one instance where PAR was adjusted using appreciative inquiry to better suit the aspirational objectives of the study.

4.2.2 Action research in Sports Coaching - developing effective practice

A collaborative approach of action research gives participants a voice and ownership over the use of new methodology, whilst giving insight into the future developments required by the researchers, as previously shown in the sport coaching literature through professional development. For example, in Clements and Morgan (2015), Pill (2014), Naslund and Penington, (2011), and in Game Sense education, Evans and Light (2008). In these studies, PAR allowed these researchers and their participants to move beyond the normative and socially constructed views that had become barriers to exploring new theory. The collaborative and democratic process in these studies allowed new theory to be applied in practice through a process that made the participants comfortable with attempting new methods.

Central to the exploration of coaching using action research, Evans and Light (2008) suggested that there are three main ways of developing coaches – informal and experiential learning, formal coach education, and action research that uses action to change methods, actions and meanings that people take from experience. This reinforces the need for the assessment of which power groups influence research and the careful design of how this input takes place. Naslund and Pennington (2011) summarised the action research process within coach development by emphasizing that the voice of the participants within research is critical to coach development, remarking that coach development environments are more effective when coaches can network, learn from, and mentor each other. The reduction of power barriers between participants and researcher by PAR supports this, whilst the framework of coach development set out by Evans and Light (2008) has guided action research that integrates new practice into existing methods. Two examples are now discussed below.

Clements and Morgan (2015) found that the collaborative approach to research of PAR was an effective coach development tool, able to enhance both learning and the in-session motivational climate of coaching sessions. Citing Martindale, Collins and Abraham (2006), the project rationale was based on the role that coaches play in talent development and the need to assess and improve the quality of the motivational environment that coaches create. Their PAR study therefore investigated how coach education could enhance the learning environment of a national talent development system. The study involved six Head Coaches operating under a Head of Performance (who was also the researcher) through a series of two and four-week cycles spanning across three months. The study triangulated individual, group and researcher reflections using coach reflective logs, focus groups and researcher field notes respectively. Within each cycle of PAR, a three-hour training session took place followed up by a focus group involving four coaches. Data within the reflective logs were used to shape the theme of the focus group discussion, with the results of the focus grouping used alongside field notes to shape the next cycle. The PAR cycles each finished with a focus group that addressed the future direction of the research, giving participants a degree of ownership over the research process. In the data analysis, a thematic analysis was used to gain meaning from the data in the project.

The study by Clements and Morgan (2015) was an example of how researcher and coach interactions could be used to advance practice over an extended period. However, given the themes of the research (addressing learning and motivational climate) it seems strange that there was no input from athletes. An athlete training log from a sample of athletes would have been a valuable addition to the triangulation of perspectives on the changes in the coach approach. Alternatively, an athlete interview or focus group within each cycle could have been used. This project was certainly collaborative between coaches and the researcher, the added input of athletes would have allowed the study to fulfill the ideals of PAR, where all stakeholders are given ownership over the development of new methods.

Similar results to Clements and Morgan (2015) were reported by Pill (2014), in a study where Game Sense was integrated into Australian Rules Football Coaching through a PAR methodology within a framework of appreciative inquiry (AI). This study was designed so that AI helped to “liberate” (Pill 2014) socially constructed thinking within coaching to integrate a positive new methodology that could improve coaching practice, achieved by integrating research into the natural setting of coaching (on the training pitch) and using action research cycles as a means by which new elements became habituated behavior for the coaches.

The use of AI in the study by Pill (2014) reframed the discourse used in a typical action research project (data collection, reflection, action – see Bargal, 2006; Baum et al., 2006; Kemmis, 2006; Andrew et al., 2013; Khan et al., 2013) with language that came from the process of directing actions through positive images (Cooperrider and Whitney, 2001), for example, the terms “Discover”, “Dream”, “Design” and “Destiny” were used to guide the research process within the PAR cycles. This gave the study a greater focus on possibilities than problems, though problems continued to be addressed throughout the collaborative process within the methodology. To ensure a thorough collaborative process, the study incorporated researcher-coach dialogue, reflective journaling and semi-structured interviews, gathered and triangulated across the duration of the 2013 Australian Rules Football season. The PAR cycles began with an initial interview that assessed the motives of the coach to adopting a Game Sense approach within their coaching practice, setting the precedent by which the reflective journaling and researcher-coach dialogue would take place during the season. The data that emerged through each PAR cycle influenced the content of the final interview, described by Pill as a “conclusion of the narrative”. Analysis of the PAR cycles was quality controlled using a coach training log and periodic observations by the researcher, and the thematic analysis of the data was member checked through with the coach after the project.

In reflection, Pill described the methodology used as allowing data to emerge from a natural situation, and whilst the thorough recording of interactions between researcher, coach, and the coach’s reflections took place, there appears to be an omission from the methodology. The study did not gather any data from athletes involved in the coaching sessions, so their perceptions of the new methodology were not part of the analysis. This was a strange omission given the democratic and constructivist roots of the Game Sense methodology being used, where questioning and conversation with athletes is used as part of an “athlete centered” learning process (Light, 2013).

The danger to PAR data in this instance, and like the study by Clements and Morgan (2015), is that in a small part, the methodology contradicted the idea of giving a “voice” to those who would not normally have one – or through the framework of Flow in this research, not seeking a validation from the whole of the *field* that exist within the *domain*. This creates a situation where potentially ineffective methods could be perceived otherwise based on the perceptions of *certain* power groups, instead of *all* power groups involved, and heightens the influence of the individual and any biases or agendas they hold. Like the study conducted by Clements and Morgan (2015), this study would have benefited from the use of athlete reflective logs or athlete interviews. Finally, while the use of AI in Pill (2014) to break down socially constructed ideas using aspirational language allowed a greater focus on possibilities than problems, there is the potential for confirmation bias with certain types of hypotheses, especially when research hypothesises that an intervention will create a perceived or actual positive effect on action.

This Chapter continues with a background on how PAR can be used to investigate WMT in sports coaching. PAR appears to be an effective method for investigating changing social environments and the impact of new practice across several disciplines. Based on the context of this research in sports coaching, the following section justifies the need for PAR in this project.

4.2.3 Using PAR to investigate the integration of WMT into Football Coaching

PAR is a methodology that can manage the process of integrating new methodology into an existing domain with the input of relevant stakeholders. The literature reviewed in Chapter 2 has presented WMT as a potentially beneficial and viable methodology for integration into Football Coaching. This theory needed to be tested by using WMT within Football Coaching to understand whether WMT can influence performance. However, before this kind of testing could take place, the practical application of WMT needed to be investigated with the input of coaches and athletes, with reference to a professional model of current practice (in this case the Game Training Model – Cross et al., 2013).

PAR has been selected to provide a framework for exploring WMT within Football Coaching by managing the interactions between researcher, coach and athlete, thus creating the opportunity to understand, apply and reflect upon feedback throughout the testing process. Through this interactive feedback process, PAR can be applied to WMT through multiple perspectives, whilst allowing changes and improvements in practice to be made and applied quickly.

The use of a PAR methodology in this research has been given further relevance due to the difficulty of performing quantitative research on the impact of WMT on football skill performance, which was not initially viable due to the lack of understanding in how we can apply WMT effectively in Football Coaching. The lack of existing application methods presents too many variables and problems that would or could affect the process of understanding the training through quantitative analysis. It was apparent when designing a data analysis protocol that without investigating the application methods thoroughly, it was not possible to account for all the potential variables that could emerge throughout the data collection process. Therefore, to investigate the benefits of WMT to Football Coaching, there needed to be an understanding of all the variables identified and how they need to be managed within practical application.

This process of investigating the application of WMT in Football Coaching required greater input from coaches and athletes, so a method incorporating interaction with the participants was required to be used. Therefore, PAR was selected as an appropriate research methodology. This development addressed the problems presented by uncontrolled and unidentified variables, whilst providing further opportunity for democratic collaboration and co-construction of knowledge between researcher, coach and athlete to develop practice by investigating how WMT could be integrated into Football Coaching.

This approach, where Flow Theory is used as a theoretical framework to understand action within PAR, allows the application of WMT to take place in a way that allows all participants (athlete, coach and researcher) to apply, reflect and develop (Baum et al., 2006) WMT practice to a point where the conditions and variables of application are found, providing a foundation for experimental research to take place Studies 2 and 3, as well as future work. Given the complex and practical nature of coaching itself, in addition to the lack of knowledge about integrating WMT, the exploration of practical delivery is an alternative to the previous use of lab-based methodologies. In consideration of the previous PAR work in coaching, where athlete input has been lacking, this research will incorporate the perceptions of athletes into the research process to achieve validation of any new methodology by those who will use it (coaches) and experience it (athletes). It is realistic to suggest that PAR is a methodology that helps integrate new methods into existing practice. In the case of this research, this means integrating WMT into Football Coaching methods, through the triangulation of coach-researcher interaction, athlete experiences/observation and analysis of video footage.

4.2.4 In conclusion of using PAR to investigate WMT in sports coaching

PAR has been presented as a method that provides the opportunity to remove socially constructed ideas or normative views as a barrier from the development of new methods, through a collaborative process that gives all stakeholders a “voice”. Through PAR it is possible to develop WMT methodology in football coaching, as demonstrated by previous work in developing new sports coaching practice, addressing buy-in issues that have surrounded the use of similar forms of dual-task training previously. The following section explains how this process took place.

4.3 Research design

The purpose of this research is to investigate how WMT can be integrated into Football Coaching using a PAR methodology. Study 1 is centered on the following research question:

- How could WMT be systemised and conducted in the context of Football Coaching?

This methodology is explained by first listing the key terms and describing the research method, followed by a description of the research setting where the methodology was used.

4.3.1 Summary of protocols and methods to be used in this research

- PAR – Participatory Action Research.
- Game Training Model – a framework for Football Coaching (Cross et al., 2013).
- WMT – Working Memory Training.
- Digit Span task – a WMT task that involves the recall of a set of items.
- N-back task – a WMT task that involves the recall of an item N places back from the current item in a series.
- Semi-structured interviews – Interviews conducted using a framework of conversation themes.

4.3.2 Method

This PAR methodology investigates the integration of WMT into Football Coaching. The use of PAR represents the need to investigate new methods collaboratively within “in-practice” situations, manipulating the power relationships of researcher and participants to address the issues surrounding “buy-in” to testing new methods. WMT has been identified as a potentially beneficial concept for Football Coaching and could be applied through a dual-tasking methodology in practice, using appropriate training principles of volume, frequency, complexity, specificity and progression – identified within Chapter 2. To represent current practice in Football Coaching the Game Training Model (Cross et al., 2013) was used as a framework for current practice.

On reflection, the process of attempting an immediate quantitative investigation of WMT in Football Coaching, and realising the flaws of the approach, the change of research design to PAR acted as a form of first cycle of action research. The process allowed the identification of the problems surrounding the investigation of WMT in Football Coaching. Based on the structure of PAR in data collection, reflection and planning, this process can be broken down as such:

- Data collection –an investigation into the use of a quantitative protocol.
- Reflection – realising that there were too many variables that could or would skew the data in a quantitative investigation, due to the non-existence of methods of applying WMT effectively in Football Coaching.
- Planning – identifying PAR as a solution that allowed the research to identify effective methods of applying WMT in Football Coaching, whilst addressing novel variables along the way.

This process set a precedent for the use of action research in future studies involving WMT and coaching. The type of data analysed in action research creates the opportunity for effectively designed experimental research on WMT and coaching to take place in the future. Furthermore, the need to investigate the on-pitch application of WMT was validated with feedback from conference presentations at the World Congress on Science and Football and Annual Congress of the European College of Sports Science during 2015, in Copenhagen (DEN) and Malmo (SWE) respectively.

The feedback from these presentations led to a presentation at Everton Football Club in Liverpool, UK, where a sixty-minute discussion further reinforced that using WMT may be desirable, but that the on-pitch application methods remained unclear. The feedback further contributed to the importance of investigating the practical application of WMT in Football Coaching and the subsequent use of PAR as a methodology that could help solve these problems.

4.3.3 PAR Cycle process

Each PAR cycle occurred around one football training session, occurring over five weeks. The application of WMT during the training sessions was based upon the WMT principles suggested in the systematic literature review of WMT.

The PAR cycle incorporated data collection, reflection and action (Bargal, 2006; Baum et al, 2006; Kemmis, 2006; Andrew et al, 2013; Khan et al, 2013) as steps in the research process. The following describes how the WMT principles were used and investigated within the PAR cycles, followed by a step-by-step description of the PAR cycles. Figure 4.1 on the following page provides a diagram that presents the design of the research and the steps that were planned or emerged prior to commencing PAR phase 1.

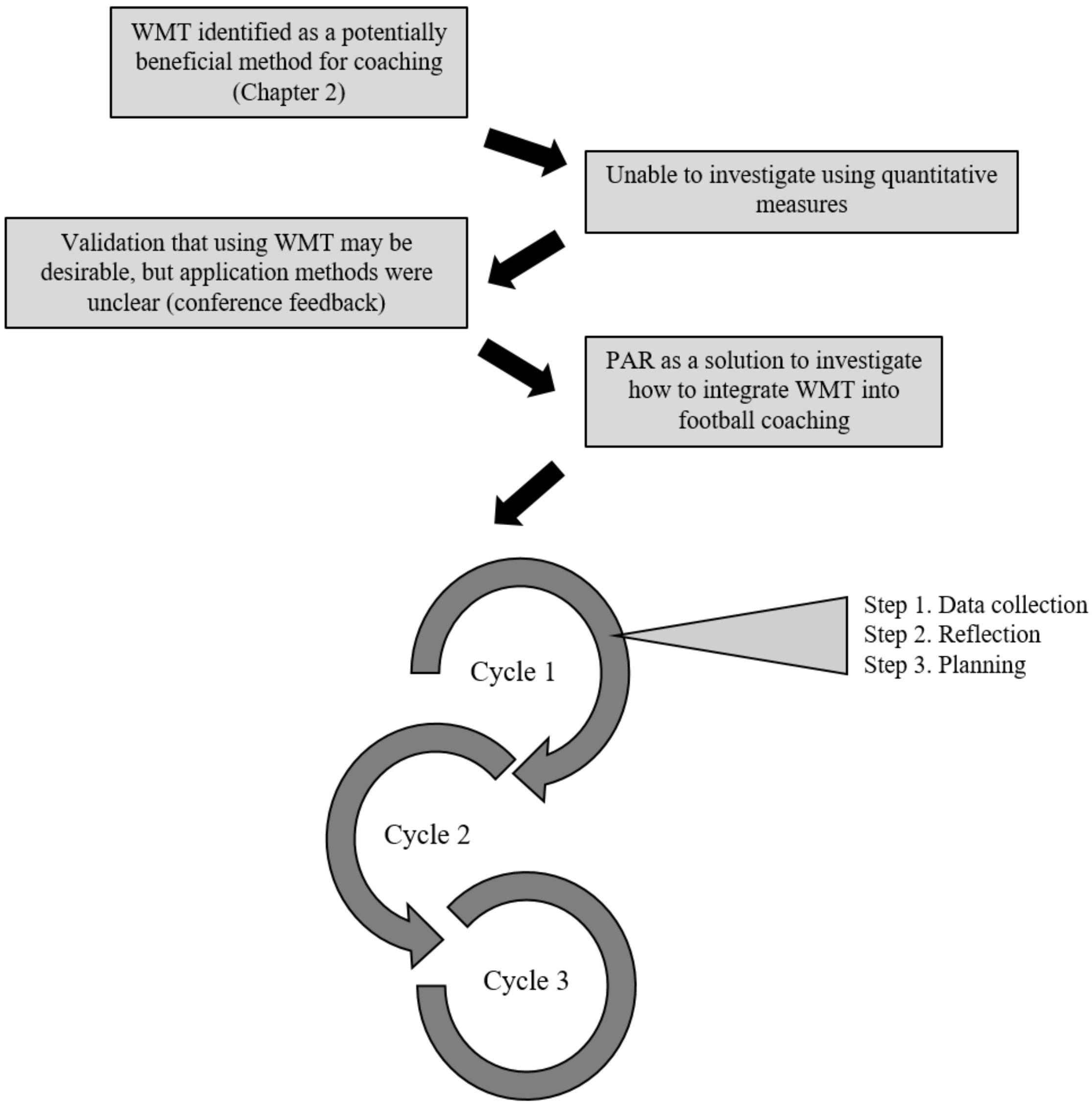


Figure 4.1 PAR design for investigating WMT in coaching

4.3.3.1 Application of WMT principles to the research process

The WMT tasks were used as a dual-task within football exercises and were delivered *as* the participant began performing an action (defined as the perception stage within the player action model of the Game Training Model). The WMT tasks required retention and manipulation of information whilst performing a player action, achieved using Digit Span and N-back tasks to load working memory. WMT was limited to one session per week (Chapters 2 and 3 identify two team sessions per week as a possibility) because this was a training method the participants were unfamiliar with. In addition, the volume was built up through the cycles (Chapters 2 and 3 identified forty-five minutes as an upper limit in volume for WMT) starting with fifteen minutes in Cycle 1, then thirty minutes in Cycle 2 and forty-five minutes in the Cycle 3. This meant that by the Cycle 3 of the research, WMT was used in Passing Practice and Positioning Game exercises.

The progression of WMT was managed by allowing the coach to observe the responses of players and adjust the difficulty (< 50% success, decrease difficulty; 50-80% success, constant difficulty; >80% success, increase difficulty) as required using pre-prepared lists of WMT tasks. Success was defined as a successful performance of a football action (as defined by the coach against the desired outcomes of the session) matched with a concurrent and correct answer to the WMT task. The training sessions were prescribed by the coach to ensure that the physical overload of actions did not take place during WMT tasks.

Each of the PAR cycles integrated WMT into practice as a dual task within the football training. This included WMT tasks, the Digit Span (Koneko, Yoshikawa and Nomura et al., 2011) and N-back (Jaušovec and Jaušovec, 2012).

To deliver the WMT tasks, the coach was provided with a list of randomly generated trials for both the Digit Span and N-back task. These trials were clearly labelled and set out sequentially in order of difficulty level. Difficulty level was defined by the length of the span task or the magnitude of *n* in the N-back task. Initially these trials were delivered orally by the coach with a verbal response from the players, however, it was anticipated that the method of delivery would change because of the PAR process. Changes in the delivery of WMT tasks are reported as part of the data analysis. The difficulty range for the Digit Span was from four to ten digits, whilst the N-back task difficulty ranged from 2-back to 4-back.

Video footage of the training sessions was recorded and captured to SportsCode software in preparation for coding. The coding system used to analyse the video footage is presented within section 4.7.

4.3.3.2 PAR Cycle Step 1: Data Collection – using WMT within the Football Coaching session

Each PAR cycle was video recorded, including interactions between the researcher and coach, and the interactions of the players and coach. Semi-structured interviews took place with three randomly selected athletes, covering the following themes; perception of personal performance, perception of challenge, and perception of WMT application in football training. Due to the competition timing required by the team (tournament preparation), and the coincidence with a university holiday period immediately after, interviews did not take place in Cycle 3 as the three selected athletes became unavailable, this was compensated for by triangulation via video analysis. Semi-structured interviews provided a balanced interview approach where it was possible to triangulate researcher observations with athlete perspective. The alternatives, structured and unstructured interviews would have limited input from either participant or researcher perspective respectively. As commented in Galleta and Cross (2013), semi-structured interviews provide the flexibility to explore specific areas of a research question whilst also allowing participants to offer new perspective or meaning.

4.3.3.3 PAR Cycle Step 2: Reflection – analyzing how WMT was applied within Football Coaching from researcher, athlete and coach perspectives

Each PAR Cycle was reflected upon by being coded by the researcher after the training session with observational notes added where applicable. Video footage was coded with SportsCode software, using a code window designed specifically for this research project, made possible due to the previous professional experience of the researcher as a video performance analyst. The code window recorded coach-researcher interactions, WMT task and difficulty, success or failure of WMT tasks and football actions, as well as the timing of the WMT delivery relative to the timing of a required football action. The design of the code window is detailed in section 4.7. In addition to the video coding, interviews were transcribed and coded for themes, which were then related to actions within the video footage. As part of the coding process, observational notes were made and attached to the relevant video clips to help understand what was happening from the point of view of the researcher.

4.3.3.4 PAR Cycle Step 3: Action – Developing new methods for applying WMT within the Football Coaching session

Following the reflection of each PAR cycle by the researcher, the following training session was adjusted by the researcher in consultation with the coach to accommodate the findings from the reflection. These changes included, but were not limited to, WMT tasks, task delivery methods, and exercise design. For example, following Cycle 1, a 7-span task was added as an additional level and a remote response system was introduced to get multiple responses to tasks at the same time, as opposed to only using WMT on one athlete at a time. Full details of changes that took place can be found in Chapter 5.

4.3.3.5 Participants

The participants were 14 male sub-elite football athletes aged 18-20, all associated with a New Zealand based University u-19 training squad. The participants were ranked based on initial working memory testing, and football ability by the coach of the team, to establish the range of ability present in the group and randomly select interview participants from three distinct ability groups. The working memory testing was conducted using eight randomized Digit Span trials ranging in difficulty from 4-span to 7-span with double digit numbers, in addition to ten randomized N-back trials ranging in difficulty from 2-back to 4-back. The percentage of correct answers was combined with the player ability ranking by the coach, listed as low, medium or high, with a 0.1, 0.2, or 0.3 value respectively. This combination gave a final value by which all players were ranked into three categories – high, medium and low. Within each category, a player was assigned a number and selected randomly for participation in semi-structured interviews using a random number generator. The following provides a brief background on the participants that took part in the interview process:

Stephen, aged 19, played football for over 10 years, participated in representative football for his province as a “full back”. *Stephen* scored 27.5% on the working memory pre-test and was ranked in the low skill group by the coach

John, aged 19, a Goalkeeper who represented his school first XI at national tournaments, participating in football for over 10 years. *John* scored 51.3% on the working memory pre-test and was ranked in the middle skill group by the coach.

Simon, aged 19, was a “center back” who had represented his province in both the NZ National Youth League and NZ National Futsal League and was considered a leadership player within this group. *Simon* scored 55% on the working memory pre-test and was ranked in the top skill group by the coach.

Alongside the interviewing of athletes involved in the research, two other participants, coach (*Wayne)* and the researcher, were involved in a consistent dialogue throughout the study. The interactions between these participants were recorded and coded as part of the reflection. *Wayne* was a coach with University coaching experience and a combination of New Zealand Football Coaching accreditation and undergraduate qualifications in sports coaching. The coach had, within 4 years of coaching experience, no experience in professional football in either a playing or coaching capacity, limiting potential experiential bias towards or away from any training methods outside of those he was formally educated in.

The researcher in the study was a 25-year-old male with postgraduate and advanced industry qualifications in Football Coaching, with coaching experience at a national level, dealing with internationally capped athletes during 6 years of coaching experience.

4.3.3.6 Research Setting

The training sessions for this research took place during late 2015 with evening time slots at the University training field. Conditions and temperature were more stable and comfortable than the winter months, creating fewer factors that could interfere in coaching delivery. All sessions were set up prior to participant arrival using clear visual aids, such as cones, agility poles and goals. Equipment used was equivalent to that used by an elite amateur football club, including fluorescent bibs for visual clarity in team exercises. There were changing areas and storage available to participants before, during, and after the training sessions. Floodlights were used as the duration of the session coincided with changes in daylight saving time.

4.3.3.7 Trustworthiness and quality standards

According to Shenton (2004), Morrow (2005) and Anney (2014), and there are four criteria that need to be considered when ensuring the trustworthiness and quality of qualitative research. The four criteria are credibility, transferability, confirmability and dependability. The following text provides a brief definition of each and links to examples of how this research satisfies those criteria.

Credibility in the context of qualitative research refers to the confidence that can be placed in the internal consistency of the research and congruence of the findings with reality (Shenton, 2004; Morrow, 2005; Anney, 2014). The quantitative equivalent of credibility is internal validity (Morrow, 2005). Credibility in qualitative research can be achieved via a number of methodological mechanisms, such as the contextual immersion of the researcher, the triangulation of data, peer scrutiny of the research process, the use of established research methods, and thick description that considers contextual factors and any beliefs that may influence the analysis of findings (Shenton, 2005; Anney, 2014).

Transferability is a controversial criterion in qualitative research, as it is the equivalent of generalisability in quantitative research (Morrow, 2005), which refers to how the findings of research apply to other contexts (Shenton, 2004). The context specificity and typically smaller sample sizes involved in qualitative research mean that the transferability of findings in qualitative research needs to be judged differently to quantitative research (Morrow, 2005). On this subject, Anney (2014) suggests that transferability can be aided by providing a thick description of the research that considers context and beliefs, whilst also selecting participants that have specific relevance to the research question. Shenton (2004) and Morrow (2005) add that the researcher must provide sufficient information about themselves in this research, providing sufficient contextual information to let the reader decide for themselves the transferability of the findings to their own context.

Confirmability refers to the adequacy of qualitative findings in the absence of objectivity that can be provided by statistics in quantitative research (Shenton, 2004). To provide confirmability in qualitative research it needs to be clear to the reader that the findings of the research are clearly derived from data and not the biases or beliefs of the researcher (Anney, 2014). Confirmability can be achieved in qualitative research via mechanisms such as audit trails (that detail the research process from start to finish), reflexive journaling and triangulation (Bowen, 2009; Anney, 2014) in addition the clear acknowledgement of any researcher predispositions (Shenton, 2004).

Dependability is described by Shenton (2004) as research being conducted in a manner that would produce the same result if repeated with the same context, methods and participants, whilst Morrow (2005) adds that the explicitness of the research process is also an important factor. Both Morrow (2005) and Anney (2014) suggest that an audit trail contributes to dependability as it provides an appropriate record of the research process, influences on the data and any emerging themes or categories (Morrow, 2005). Shenton (2004) also emphasises the need to critically appraise the effectiveness of the research process. As an additional reflective lens, Anney (2014) also suggests the use of peer examination during the research process.

This research satisfies trustworthiness and quality standards, based on the literature detailed above, through the following mechanisms:

- Immersion of the researcher in both the profession of coaching and the pedagogical framework of football coaching (the Game Training Model – Cross et al., 2013) used in the context of this research.

- Triangulation of data between video, researcher and participant with reference to both a review of literature that informs the description of action, and a theoretical framework that allows the context of the research to understood as a system.
- Use of a collaborative action research methodology that has previous use cases of investigating new practice in sports coaching research – for example, Evans and Light (2008), Pill (2014), Clements and Morgan (2015).
- The thick description of the context of the research, researcher and participant bios, the research methodology and pedagogical framework used in the research.
- The chronological presentation of the research process in Chapter 5, demonstrating how the themes and categories emerged throughout the research process.
- Supervisor collaboration during the data collection process, ensuring that the intended methodology was executed correctly.
- Reflection on limitations and assumptions of the research process both before and after the data analysis.

4.4 Ethics

A challenge identified in this research was providing a current practice environment whilst testing the intervention method as an addition, as it would be unethical to deliberately negatively affect or change current practice, for the purpose of testing a method solely for the interest of research. This was solved by using the Game Training Model (Cross et al., 2013) within the study to ensure that the training sessions were constructed with a well-researched process, as well as the use of PAR to give the coach voice over how the training would be conducted. This limited the probability of training becoming a negative experience for the participants involved, whose primary reasons for participation included enjoyment and socialising, alongside improving and preparing for a tournament.

An additional challenge was to maximise the effects of the WMT whilst minimising the influence or potential bias of the researcher, especially considering the role of the researcher as a participant in this study. A second challenge raised questions regarding the power relationship between the researcher and participants (Eide and Kahn, 2008). Due to the difference in qualifications and experience and the potential effect of this on the power relationships within the research, the researcher did not engage in a pedagogical, technical or physiological discussion with the coach during the sessions. All discussions were related to the use of WMT within the session the coach had designed. The coach did communicate the session plans prior to training, simply for organisational purposes. Furthermore, for this study PAR was selected as it provides a structure where power is shared evenly between researcher and participants, presenting a solution to this issue. The methodology was designed to limit the setting, timing and subject matter of interactions between the researcher and participants. Athletes were only approached for comment outside of the training sessions to remove any perceived power relationships between researcher and participant.

The research was approved through a low-risk application process as a mixed methods study. The research was considered low-risk because the application had no specific cultural implications - cultural information was not recorded and there were no culturally sensitive practices or artefacts involved. There were no invasive procedures, nothing involving personal or sensitive issues or vulnerable groups. No prior information outside the public arena was used, and informed consent was obtained from all participants. There was no conflict of interest and any audio-visual recordings were undertaken with prior consent. The participants benefited from a current practice coaching program and therefore did not have any guaranteed benefits withheld. There were no inducements to participate, no deception and no prior information on participants was collected. The training program presented no greater risk to participants than they would encounter under their normal participation in football. Measures normally taken to ensure the safety of athletes when participating in football were undertaken – including warm up, cool down and loading strategies.

As detailed in the ethical application:

- Participants in the research were of an amateur nature, as such, not all participants were present for all sessions in the intervention due to their own lifestyle demands. Given the nature of the data being collected, the interviewed participants were present for each session so there was little issue with some participants not being present for all sessions.
- Participation was voluntary, and participants had the right to withdraw at any stage without penalty. All data was removed where practical when requested specifically. Interviews were audio recorded and transcribed, and participants given the opportunity to member check the transcripts and any amendments were made. On request, participants were able to receive a copy of the project results by contacting the researcher after the project.
- There was complete confidentiality of data gathered in this investigation - participant identity was not made public without prior consent. To ensure

anonymity and confidentiality, pseudonyms were used for all participants. Data was kept in lockable storage in a secure facility at the University of Canterbury and all electronic data was be password protected. Data from this study was only seen by myself and academic supervisors Prof. Nick Draper, Prof. Jeanne Kentel and Prof. Niki Davis. Data is kept in secure facilities at the University of Canterbury for ten years following the study, after which time it will be destroyed.

4.5 Limitations and assumptions

The use of sub-elite athletes created a limitation whereby the availability of athletes was limited following the end of Cycle 3 due to the end of the academic year, leading to a lack of interview data following Cycle 3. The gap between action and interview could have led to a less accurate recollection of events by participants, compared to the interviews in previous cycles that occurred within 24 hours of the training sessions. This was mitigated by triangulating the Cycle 3 based on video analysis, researcher-coach dialogue and researcher notes. In addition, a limitation of qualitative research, in general, is that it is difficult to generalise the findings to a wider population, applying in the case of PAR due to the focus on rich data collection from a small number of individuals who are assumed to have interest in the research itself.

In pursuing this project, some assumptions were made regarding the methodology. One assumption was that the pedagogical approach being utilised was representative of current practice in terms of Football Coaching pedagogy. With this assumption in mind, the use of WMT in this project appeared to be fit for performing this research, because it was intended as the sole addition to what is already considered to be current practice. A second assumption is that the coaching style and strategies utilised by the coach were also representative of current practice. This assumption can be made based on the qualifications and experience of the coach involved.

It is anticipated that this research will set the basis for future study in professional environments, in the same manner that small-sided game research in football moved from amateur youth (Hill-Haas, Coutts, Rowsell and Dawson, 2008) to professional level (Owen, Wong, Paul and Dellal, 2012). In addition, it is anticipated that this research will benefit future methodological approaches to investigating the use and effects of WMT in coaching.

4.6 Summary – Using PAR to investigate and develop WMT within Football Coaching

WMT presents a potential innovation in the development of sports coaching practice. The use of WMT is presented with challenges in effective practical application as well as social acceptance from those in the field. To address these challenges, it is necessary to test the application of WMT within the Game Training Model. Using PAR to investigate, as an emergent and collaborative methodology, meant that coaches and athletes can be given an active voice in the development and integration of WMT within Football Coaching. This approach simultaneously allows the testing and development of new methods, whilst reducing the effect of normative views as a barrier to innovation through the empowerment of those who will experience, and be affected by, the use of WMT in Football Coaching. The use of PAR allowed the researcher in this project to democratically manage power relationships effectively, so that perceived status or influence did not impact on the generation of new knowledge, whilst protecting the confidentiality rights of those involved. The cycles of PAR enabled this research to collect data through video recorded practical sessions, reflect on practice using interviews, observation and conversation, and provide new ways of using WMT within Football Coaching that considers the “on-pitch” issues that are faced by coaches and athletes. This methodology lays that foundation for future research into the application and effectiveness of WMT using a wide range of methodologies. The following section demonstrates the data analysis in Study 1, which is then detailed in the following Chapter.

4.7 Reading the data analysis

This section describes how the video was coded and demonstrates how the data is presented to aid understanding of the data analysis. This includes examples of the data analysis presented in Chapter 5, including coded interview excerpts and researcher notes. As part of the reflection step within each PAR Cycle, video footage was coded using SportsCode software to allow video data to be triangulated with interview data from participants and the interactions of the researcher and coach. This section begins with a description of how the theoretical framework was applied, using an example from the data analysis. This section continues with a description of how the video was coded, ending with an annotated example of how the data analysis is presented in this Chapter.

4.7.1 Applying Systemic Creativity and Flow as a theoretical framework

As detailed in Chapter 3, Csikzentmihalyi's Systemic Creativity and Flow theory have been used as a theoretical framework to understand action. Table 4.1 presents how the theoretical framework applies to the data analysed in this Chapter:

Table 4.1 Application of Flow Theory and associated systems and terms to the context of this study

Concept	Term	Application
Systemic Creativity		A framework that describes the socio-cultural structure of action
	Domain	Football Coaching
	Field	Collective perspective of coach, participant and researcher
	Person	Individual perspective of coach, participant and researcher
	Entropy and Creativity	Entropy – using existing pedagogy Creativity – exploring new pedagogy
Systemic Creativity		Used to contextualise each theme of the data analysis within the Mesosystem, Macrosystem and Microsystem that affect action.
	Mesosystem	The team culture and expected team behaviours.
	Macrosystem	The objective conditions of each activity – tasks, rules, constraints.
	Microsystem	The internal perceptions and processes of the participant when performing actions.
Flow Characteristics		The conditions and experience that lead to, and occur, during a Flow state.
	Clear goals at each step	Successful completion of a WMT task with each football action required.
	Immediate feedback to action	Internal and external feedback, the participants immediate perception of why a WMT task or football action was successful or unsuccessful.
	A balance of challenge and skill	Use of the difficulty algorithm identified in Chapter 2 to correctly balance the difficulty of handling both the football action and the WMT task.
	Merged action and awareness	Feeling of automacity during football actions and WMT tasks
	Exclusion of distractions from consciousness	Full attentional allocation to the WMT task and football action – using both WMT and the football action to occupy all available working memory capacity during an action
	No fear of failure	Perceptual experience of the participant where they only considered succeeding at performing actions and were indifferent to non-desired outcomes.
	Distortion of time perception	Perceptual experience of the participant where action seems to slow down or speed up.
	The activity becomes autotelic (self-fulfilling)	The perceptual experience of the participant where performing an action well is an objective, separate from any wider outcomes, such as goals scored or conceded.

4.7.2 Video coding

Video of the training sessions in each cycle was completed in order to allow the coding and analysis of action occurring within each cycle, which could then be triangulated with researcher and participant perspectives. Table 4.2 shows how each video was coded, demonstrating how different aspects of the training session were recorded.

Table 4.2 The coding system and code labels used to analyse the video footage.

Code Type	Code	Description
Coach-Researcher interaction	N/A	Interactions between the researcher and coach during data collection
Researcher Comments	N/A	Relevant comments made by the researcher during the data collection
Task	N/A	The WMT task used during the action, i.e. Digit Span or *N-back*, numbered based on difficulty
	DS 4	Digit Span task with 4 single digit numbers
	DS 5	Digit Span task with 5 single digit numbers
	DS 6	Digit Span task with 6 single digit numbers
	DS 7	Digit Span task with 7 single digit numbers
	DS 8	Digit Span task with 8 single digit numbers or four double digit numbers
	2-back	N-back task where the participant had to recall matching items in a sequence that were two spaces apart – for example, the sequence **2**3**2**4**5**6**5**, where items 1, 3, 5 and 7 in the sequence are examples of matching 2-back items.
	3-back	N-back task where the participant had to recall matching numbers in a sequence that were three spaces apart – for example, 2**3**2**43**5**4**66
	4-back	N-back task where the participant had to recall matching numbers in a sequence that were four spaces apart – for example, 232**4**351**4**65
Code Label Type	Label	Description
Timing	N/A	The timing labels describe when the WMT task began relative to the timing of the concurrent football action, as defined by the Player Action Model (Cross et al., 2013) in Chapter 3.
	Pre-Action	The WMT task was delivered just before, or at the start of the football action (perception stage).
	Mid Action	The WMT task was delivered after the start but before the end of the football action (decision making stage).

	Post Action	The WMT task was delivered at the end, or after the end of the football action (execution stage).
Football action	N/A	The actions of the participants as defined by the Player Action Model (Cross et al., 2013) – for example, passing, shooting, dribbling.
	Successful	The football action of the participant was successful – for example, a completed pass to a team mate or shot on target at the goal.
	Unsuccessful	The football action of the participant was unsuccessful – for example, an incomplete pass to a team mate or a missed shot at the goal.
Response Type	N/A	The method that was used to gain a response to the WMT task
	Verbal	The WMT task response was verbal
	Successful	The verbal response to the WMT task was correct
	Unsuccessful	The verbal response to the WMT task was incorrect
	Remote	The WMT task response was made using a remote
	Successful	The remote response to the WMT task was correct
	Unsuccessful	The remote response to the WMT was not correct

Researcher notes were added to the coded and labeled videos during the reflective process, presenting the perspective of the researcher on the action. In some cases, these notes were included with a dialogue summary that was used to describe the nature and /or outcome of researcher comments or coach-researcher interaction that occurred during the data collection. Figure 4.2 below provides an example of how the codes and code labels are presented in the research along with researcher notes.

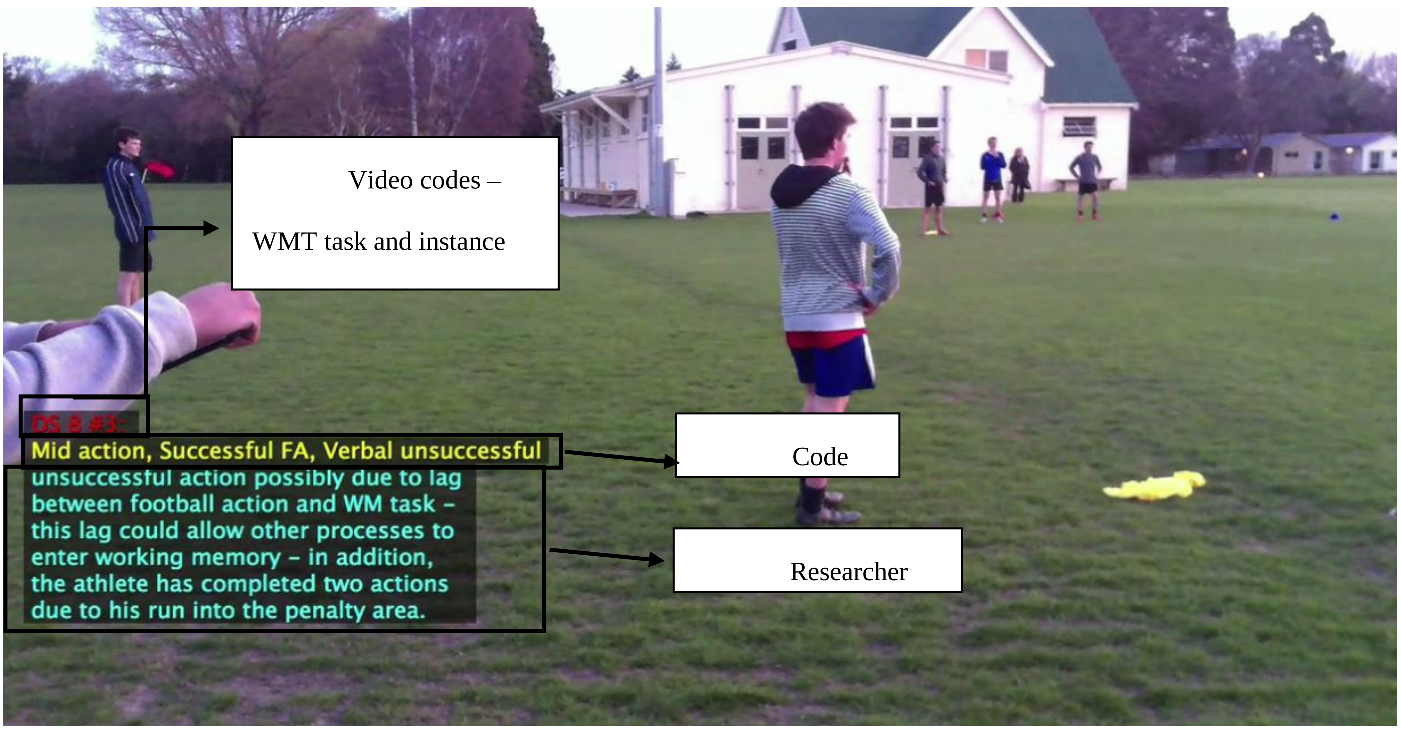


Figure 4.2 A screenshot of coded video displaying video codes, code labels and researcher notes.

4.7.3 Interview coding

The interview data gathered from participants were coded based on topics that emerged during the reflective process, making this an inductive approach. During the reflection, three topics emerged and shaped how the development of WMT within Football Coaching would occur over the course of the research. The three topics that emerged were WMT Task delivery, WMT Difficulty and WMT Task Process. WMT Task Delivery encompassed interview data that referred to how the tasks were being delivered within the sessions, including the perspectives and discussion of participants on effective, ineffective and possible ways of delivering the WMT tasks during the training session. WMT Difficulty covered interview data that referred to how the use of WMT tasks impacted training difficulty, including effects on football actions. Finally, WMT Task Process was a topic that included interview data where participants described their internal experience and perspective during the training session when attempting WMT. This final topic was vital to the research, as internal processes or experience are not necessarily observable from a video or researcher perspective.

Data within each of these topics was made identifiable within the transcripts using a colour coding system. The colour coding system for each topic was as follows:

- WMT Task Delivery
- WMT Task Difficulty
- WMT Task Process

Following the color-coding of interview data, data was organized thematically by placing related data together to disseminate the most common themes that emerged within each Cycle from the perspective of the participants. Excerpts from the transcript are presented within the relevant theme without the colour coding, as it is used here merely to demonstrate how the data was coded. An example of the colour coded thematic data can be seen below, where data from Cycle 1 in the WMT Task Delivery category is presented:

- Consistent volume and cadence are required when delivering WMT tasks verbally
    - I found it hard at the start. I think it would be a good way …. I think it would be easier when you are doing more closer quarter passing rather than we were doing quite a big exercise and it was quite far for the numbers to reach, loudness comes into it. (Simon)
    - Definitely slow and loud was easier, though not too slow for you to forget by the time they are finished being read out. I think the rhythm mattered a lot when repeating numbers to yourself, you mirror how they say it to you, so easier when it‘s nicely spaced (Stephen)

The thematically organized interview data was then triangulated with video where possible. As the data varied between comments on specific instances and more general comments, Chapter 5 first presents specific instances of triangulation between interview and video data. This is followed later in the analysis of each Cycle by the presentation of general interview data that supports the triangulated data. This is important due to the difficulty of capturing the internal processes and perspectives of the participants using video footage, giving the interview data significant weight within this analysis where the topic of WMT Task Process is discussed.

4.7.4 A full example of data analysis in this study

This section provides an example of the data analysis in Chapter 5, acting as a practical summary of the previous sections describing how the analysis was performed. The video is presented first, with the associated coding, labels and notes added underneath. This is followed by a qualitative description of the action. The video opens in a new window when clicked.

Video 5.4 DS 5#2

Video number, code, instance no. and time at which the video was captured

Coding – DS 5

Code – Task type and

Labels – Mid action, Unsuccessful FA etc.

Labels – timing, football action, WMT response type

Notes – unsuccessful football action due to bad passing by previous player

Notes made by the researcher when observing the video

Chapter 5

Study 1: Applying WMT in Football Coaching using PAR

This Chapter is a chronologically ordered and interactive description of the PAR cycles carried out in this research, following the methodology described in Chapter 4. The analysis of each cycle is described in a thematic structure, with the themes that emerged the most from each session placed first, descending to the themes that emerged the least, based on the repeated triangulation of data. This is designed to detail the emergent nature of this research and the journey that took place throughout, giving clear steps and reasoning as to why certain actions were carried out, whilst also giving a clear picture of how themes emerged.

The description of Cycles 1, 2 and 3 is presented, split under subheadings that detail the data collection, reflection and planning steps, as described in Chapter 4 (Bargal, 2006; Baum et al., 2006; Kemmis, 2006; Andrew et al., 2013; Khan et al., 2013), that took place within each Cycle. The data collection subheadings include thematically ordered videos from the training sessions that have been triangulated with interview data and researcher notes. In the interest of being concise, each theme will contain the video that is the clearest example of the theme being discussed, with the coding of further videos listed for further reference where required.

The reflection subheadings include additional data that either add value to the observations within the video, or describe internal factors that aren't necessarily observable on video. The reflection subheadings conclude by categorising the themes and discussing the implications of each. The planning subheadings describe the implications on the next Cycle of research. To conclude the data analysis, a section containing the tabulated outcomes and notes is presented, followed by a conclusion that leads into the discussion in Chapter 8. Figure 5.1

provides a diagram that shows the structure of the data analysis presented in this Chapter, showing both the linear presentation of research, and the depth of analysis presenting in each Cycle:

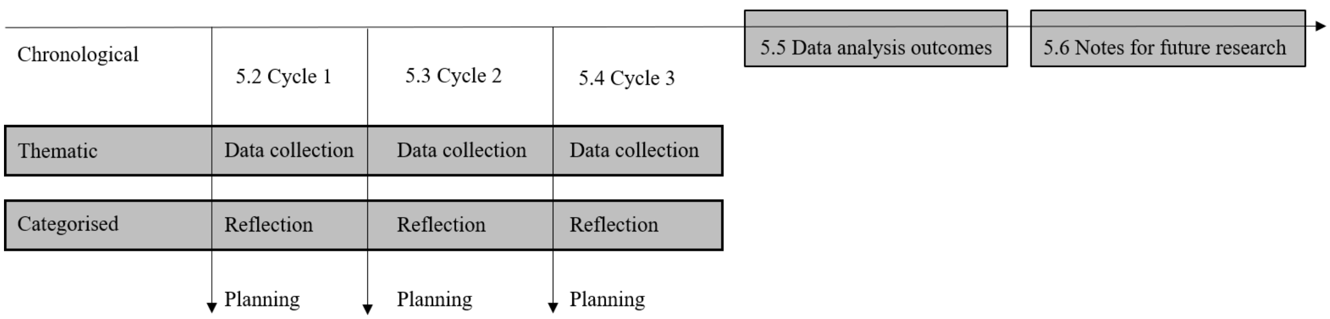


Figure 5.1 Study 1 data analysis structure

5.2 Cycle 1

The process of planning action for Cycle 1 considered the literature reviews in Chapter 2 in combination with the conceptualisation of using WMT in the Game Training Model, presented in Chapter 3. In practical terms, this meant the following:

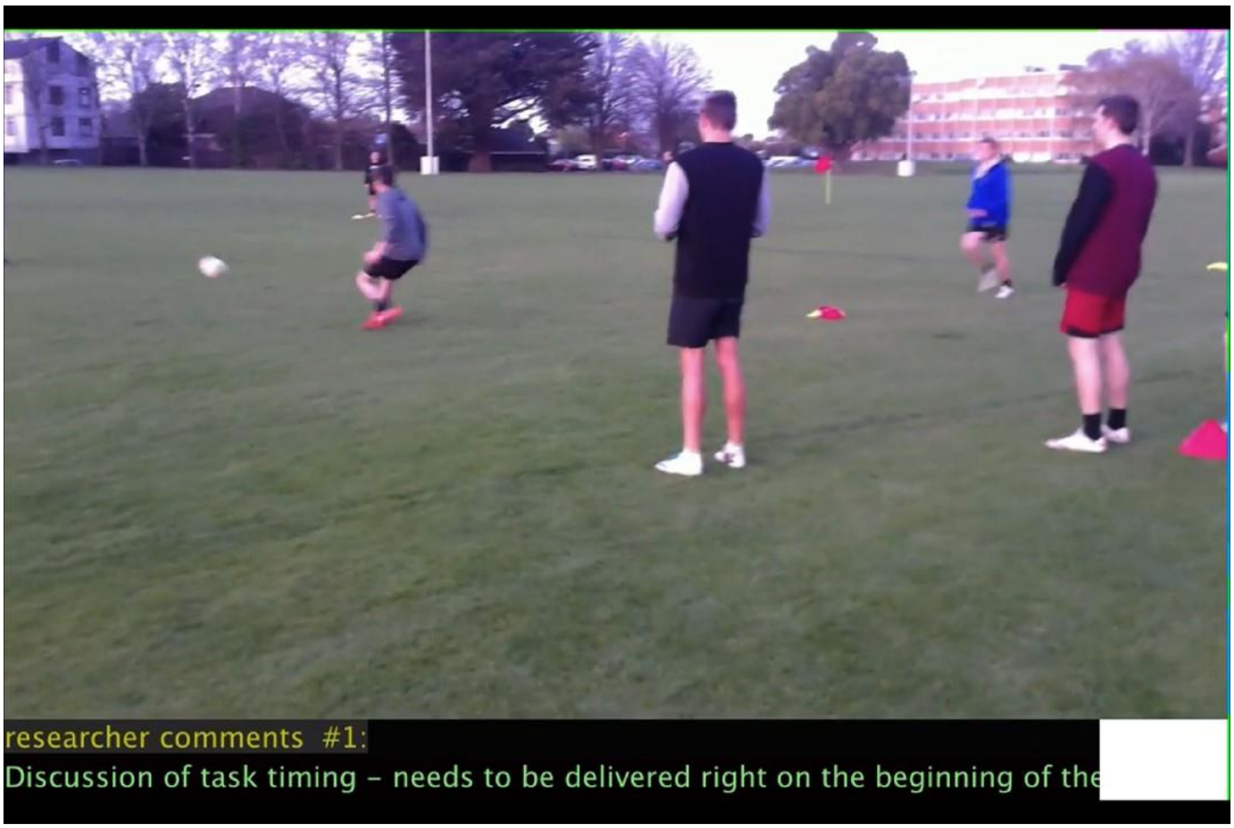
- Fifteen minutes of training was delivered as a representation of a minimum dose of WMT in a session, considering the need for the participants to adapt to and accept the use of WMT.
- The WMT was applied to player actions completed in the Passing Practice.
- The Coach was provided with WMT tasks that spanned from low difficulty (four-span) to high difficulty (eight-span) so that the difficulty of the tasks could be adapted to the success of the participants on the tasks.
- WMT was delivered verbally, with a verbal task response required back to the Coach, this was the minimum viable way of delivering the tasks.

The above conditions and their theoretical underpinnings were discussed with the coach (*Wayne*) prior to the session, giving *Wayne* the opportunity to influence how the session was planned and delivered with WMT integrated.

5.2.1 Training session 1

This section is thematically organized analysis of the data collection in Cycle 1.

5.2.1.1 Theme – Macrosystem - it is necessary to time WMT delivery at the beginning of the football action (perception stage) to overload working memory during the football action



Video 5.1 researcher comments, #1

Coding – researcher comments

Dialogue summary – Discussion of task timing – needs to be delivered right on the beginning of the action

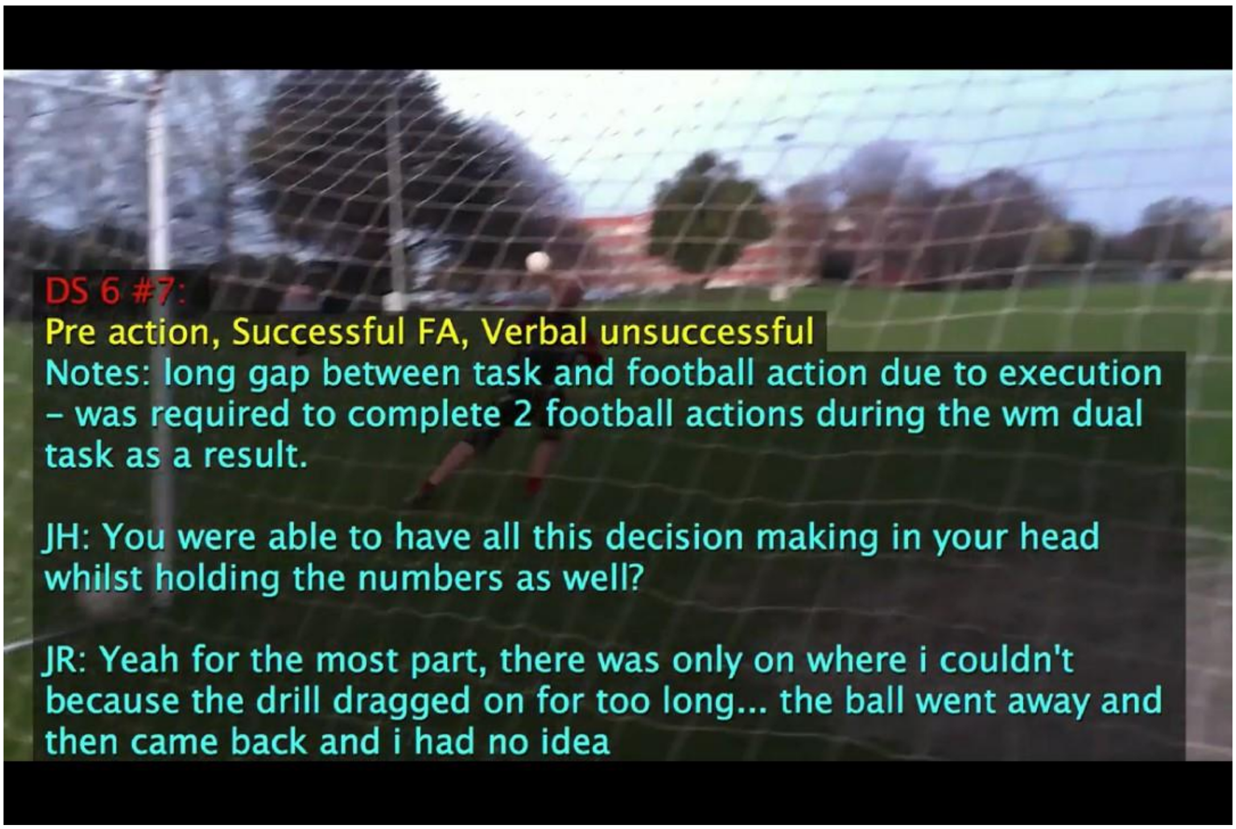
Description and Analysis

Video 5.1 is an example of how PAR methodology is used to manage power relationships and give participants the chance to influence practice. The coach has started experimenting with WMT and changed the task delivery to the start of the football action. The researcher was then able to make note of the change and its influence on practice without any need to interfere with the coaching session. This has allowed the theme of timing the task correctly to emerge organically, with its status as a solution emerging from observation of the action itself.

Timing the WMT task at the start of the football action means that the participant is solving the WMT task during the whole of the football action. During the perceptual stage of an action, stimuli are selected to enter working memory (per BCT). The presence of a WMT task during the perceptual stage means that some of the available working memory capacity during the action is occupied before stimuli can enter working memory. This means that the subsequent processing of the action in working memory (manipulation of the stimuli, reference to long term memory and integration of a motor task) is forced to occur using less activation throughout the entire action. In contrast, delivering the WMT task after the perceptual stage would mean that activation is first used to process stimuli and the subsequent decision making and execution processes, with remaining activation used to process the WMT task. This makes it more difficult to process the working memory task, as opposed to making it harder to process the action – which is desirable from an implicit learning perspective. The objective of using WMT during Football Coaching is to improve the football actions of the participant whilst concurrently improving domain-specific working memory capacity. Therefore, the priority is to perform the football action with limited activation, as opposed to performing WMT with limited activation, thus, delivery of WMT is desirable at the start of the football action, not during.

The task response needs to occur immediately after the specific football action.

Video 5.2 DS 6 #7



Coding – DS6

Labels – Pre action, Successful FA, Verbal unsuccessful

Researcher notes – Long gap between task and football action due to execution, was required to complete two football actions during the WM dual task as a result.

Interview notes –

Researcher: “You were able to have all this decision making in your head whilst holding the numbers as well?”

John: Yeah for the most part, there was only one where I couldn’t because the drill dragged on for too long… the ball went away and then came back and I had no idea

Additional videos: DS 8 #3

Labels – Mid action, Successful FA, Verbal unsuccessful

Researcher notes – unsuccessful football action possible due between the football action and WMT task, this lag could allow other processes to enter working memory, in addition, the participant has completed two actions due to his run into the penalty area.

Description and Analysis

Video 5.2 demonstrates how the overload of a football action provided by WMT needs to be understood specifically as the overload of *one* action. The participant is a goalkeeper, the football action is defending a cross from the opposition. The WMT task is delivered as the opposition player began the action of striking the ball, where the goalkeeper will start perceiving cues from the body position and technique of the opposition player. Therefore, the action of defending the cross was overloaded using the WMT task. However, because the ball travels to the back post, missing one opposition player, a second football action from the goalkeeper begins; defending a shot from an opposition player. The goalkeeper was able to perform this action correctly but was unable to answer the WMT task correctly from the first action. Notably, the time that elapsed between the WMT task delivery and answering the WMT task was approximately twelve seconds, which could have been too long for *John‘s* working memory to hold the information from the task - therefore it was not necessarily an overload of working memory which caused him to fail the WMT task, rather, the length of time required before answering the task. *John* alluded to this in his interview;

> "…there was only one where I couldn't because the drill dragged on for too long… the ball went away and then came back and I had no idea." (John)

Furthermore, this excessive duration could mean that the second action (defending a shot from an opposition player) may not have been overloaded as intended. So, whilst the action was successful, and *John* was able to save the shot, an opportunity to improve the action by using WMT tasks was missed.

The other implication is the negative internal feedback from failing the WMT task. Despite performing a successful action, *John's* body language after saving the shot, failing the WMT task, was as if he had not performed a successful action. Therefore, it is important for both coaches and participants to understand that WMT is used to overload actions on an action-by-action basis, which has further implications in helping participants to stay "within the moment" of performance, letting go of failure and always focusing on the task at hand.

To conclude, Video 5.2 demonstrates that when a second action takes place, a second WMT task needs to be used to overload the second action. This can also help to avoid misinterpreted internal feedback by the participant, or a misinterpretation of why a task was failed by the coach.

5.2.1.2. Theme – Macrosystem – When delivering WMT tasks verbally, it is easier to make the task delivery effective by focusing on one player with a specific action

Video 5.3 Coach Researcher, #2

Coding – Coach Researcher

Researcher notes – Deciding how to deliver the tasks and gain a response. Decided on delivering the task to one player at a time, targeting a specific action in the exercise.

Additional videos: researcher comments, #7

Coding – researcher comments

Dialogue summary – Easy to work with a GK as he is situated in one area all the time, making verbal delivery of tasks easier.

Description and Analysis

Video 5.3 demonstrates two things – firstly, that the verbal delivery of WMT within football training presents constraints in ensuring that coaches can deliver the task correctly and that participants are able to hear the task correctly. Secondly, Video 5.3 reinforces how the use of PAR methodology allowed the coach to create a dialogue with the researcher about how to deliver the tasks effectively, and furthermore, how the researcher could empower and enable *Wayne* to comment on and adjust practice by using a questioning approach.

In this video, *Wayne* discovered the difficulty of delivering a WMT task verbally to a group of players, with the right timing to overload the actions of each participant involved. Therefore, a consensus was reached to focus on using the WMT tasks to overload one player on a specific football action. This allowed *Wayne* to stand closer to the participant when delivering the task, ensuring that the task was heard correctly.

After questioning the researcher in this video, *Wayne* had a significant pause, before turning back to confirm what he wanted to do. This pause was presumably to finalise his solution to the problem of delivering the WMT task effectively and is an example of how the use of PAR allowed *Wayne*'s input as a coach to help develop new practice.

5.2.1.3 Theme – Macrosystem – Consistent volume and cadence are required when delivering WMT tasks verbally

Video 5.4 DS 8 #5

Coding – DS 8

Labels – Mid action, Unsuccessful FA, Verbal unsuccessful

Researcher notes – Distance possibly an issue, hard to hear the numbers?

Interview –

Simon: "I think it would be easier when you are doing more closer quarter passing, rather than we were doing quite a big exercise and it was quite far for the numbers to reach, loudness comes into it".

Additional videos: DS 4#2

Labels - Pre action, Unsuccessful FA, Verbal Unsuccessful

Notes – There was a pause in the delivery of the numbers – it is possible that this pause allowed other conscious processes to enter working memory, interfering with the football action and working memory task, resulting in the failure of both.

Description and analysis

Video 5.4 demonstrates the impracticalities of using verbal delivery for WMT when working in larger exercises. The use of WMT will be limited to the individual, as the use of WMT with the player who crosses the ball in this video would mean delivering the task to a player a long distance away, or the coach having to change position to an area that is not ideal for observation of the whole exercise. In this video, the coach is using the task with a player who is moving away from him. The player repeated an incorrect series of numbers to the coach and it was unclear whether it was due to the difficulty of the task, or because the player did not hear the task correctly. Because of this inability to assess why the answer was incorrect, it was not possible to assess whether the task was of appropriate difficulty for the participant.

Furthermore, there is a brief discussion at the start of the video with the coach regarding the speed at which the Digit Span tasks were read out. *Stephen* alluded to the need for a consistent cadence and volume when performing the WMT during his interview.

> “Definitely slow and loud was easier, though not too slow for you to forget by the time they are finished being read out. I think the rhythm mattered a lot when repeating numbers to yourself, you mirror how they say it to you, so easier when it’s nicely spaced.” (Simon)

Therefore, Video 5.4 showed the need to develop strategies that will guarantee the consistent aural delivery of WMT to the player, a need explored in later phases of this research. By solving this problem, it will then be possible to assess correctly the difficulty of tasks and whether a player is answering the task correctly or incorrectly.

5.2.1.4 Theme – Microsystem - When determining whether the associated football action during WMT is successful or unsuccessful, the previous action from other players needs to be considered

Video 5.5 DS 5#2

Coding – DS 5

Labels - Mid action, Unsuccessful FA, Verbal successful

Researcher notes – unsuccessful football action due to bad passing by the previous player

Additional videos: *DS 4, #4*

Coding – DS 4

Labels - Unsuccessful FA, Verbal successful

Researcher Notes – Unsuccessful football action likely due to bad positioning decision prior to WM task, as well as bad pass execution by previous player.

Description and analysis

Video 5.5 shows how other factors aside from WMT can impact the success of football actions and/or WMT tasks. Due to the bad pass by the previous player it was not possible to complete the required football action, and therefore the WMT task became irrelevant. It is therefore important to assess the difficulty of the exercise, the execution of the players, and the impact these factors have on football actions. Players need to be able to complete the exercises and actions competently before WMT is introduced. This example highlighted the minority of actions that took place within the exercise, but in principle, was important in the wider scope of the session.

5.2.1.5 Theme – Microsystem – individualising the WMT difficulty correctly is more difficult when working with a large group

Video 5.6 researcher comments, #3

Coding – researcher comments

Labels – verbal successful

Dialogue summary – speculating what the best span-task difficulty will be for the group. Researcher notes – This depends on the range of abilities between individuals, as well as the difficulty of the exercise. There won't be a one-size fits all difficulty across different exercises. Instead, exercises need to be repeated with the WMT difficulty recorded and used specifically for each.

Additional videos: *researcher comments, #6*

Coding – researcher comments

Dialogue summary – need a 7-span task, considering the benefits using of double Digit Spans at higher levels instead of single Digit Spans

Description and analysis

The dialogue and notes associated with Video 5.6 demonstrate how individualising WMT for players during exercises is a complex task. The researcher was speculating what difficulty might be appropriate for the group based on the success of the football actions. However, this can only be adapted to the mean or median ability of the group. Using one difficulty for an entire group will mean, depending on the range of ability, that the best players may be completing WMT that is too easy, whilst the worst players may not be able to complete the WMT at all. Hypothetically, one difficulty could be used if a group of players was very close in ability, but even then, the use of one difficulty could only be applied during general exercises due to the domain and role specific nature of football training, as players of similar overall ability may still have qualities better suited to defending or attacking and will therefore have varying success across different exercises. These differences in player characteristics mean that methods of delivering WMT with individualised difficulty during team exercises need to be explored.

5.2.1.6 Theme – Microsystem – 'shared attention" between WMT and football actions: experiences of the players

Due to the nature of observing Perception, Decision Making and Execution in the field as *external* actions, it is not possible to observe the *internal* processes that the participants experienced very easily. Therefore, this theme focuses on the internal process experiences of the participants when performing actions in the training, data for which was observable within the interviews, based on the understanding of action processes and the relationship between Working Memory and performance. This is a triangulation of research literature, interview data and researcher observation.

The application of WMT in this research was like that of dual tasking, with the added benefits of stimulating plasticity of working memory related structures in the brain. The term "dual tasking" defines that two concurrent tasks are taking place during the performance of an action, so it is of little surprise that participants reported experiences like this definition. In the case of this research, action refers to the football action being performed, which involves Perception, Decision Making and Execution in relation to the apparent game moment, key principle, team tasks and player tasks. This model therefore provides a framework for us to understand the influence of WMT on the performance of the football action. The following presents interview data relating to participants perceptions of the internal processes experienced when performing WMT as a dual task alongside a football action.

Firstly, evidence of a participant performing two concurrent tasks, as defined by dual tasking:

> "Because I had to repeat the numbers after the phase or drill had finished, it was a necessary distraction I had to keep on board." (John)

This excerpt highlights that *John* felt that he was engaging in a concurrent task whilst performing football actions. The word "necessary" suggests ownership over completing both tasks at the same time, whilst "distraction" suggests interference with the actions he was trying to achieve.

> "That's the sort of cues you've got to focus on, is that positioning and which number players, then once the ball's in the air and the numbers were coming in, was "do I go and catch this, do I not?" and from that it's "where do I position myself now and what am I expecting", so just expecting where it would be a header or volley. You don't take that stuff too seriously, but you have to keep it." (John)

This was an example of a dual tasking / WMT experience whilst performing a football action, as the first two stages of the football action model are described by *John* in his interview. "Cues" is a referral to the perception stage of action, then "do I go and catch this…" refers to the decision-making stage. This is observable because *John* was able to clearly verbalise the cues he perceived and the resulting decision-making process. *John* describes WMT in this instance as beginning later in the perceptual stage, after recognizing the positioning and number of other players involved in the action. Finally, "keep it" may refer to holding the action process whilst completing the dual task. This is therefore evidence of WMT influencing a football action.

> "But, it still wouldn't have affected the defender or someone else, but because it was just numbers, it didn't have any say on how I was executing what I had to do. Yeah, as long as I was just in the right position it didn't affect my mind set, I felt that I could, um, do everything as normal in terms of saving the ball." (John)

This quote from *John* described the balancing of the football action with performing a dual task, with the added acknowledgement that the WMT did not impact on what perception, decision- making, or execution took place, rather, it impacted on his ability to progress through those three stages without changing the end outcome. There was also reference here to the importance of difficulty, had the task been too hard or too easy, *John*'s description of events may well have been different, with a breakdown of action or lack of any effect respectively possible.

> "I feel like I probably did a little worse because not all my brain power was going to the numbers, I was focusing on the ball." (Stephen)

Stephen's account described how a difficulty imbalance can work both ways. The football action was too difficult to allow him to complete the WMT task as well – the same principle as having a WMT task that is too difficult and creating an action breakdown.

"I actually found the execution, I don't know, it felt kind of better because you weren't overthinking what you were doing, which I sometimes find a problem. I don't think it impaired it at all, which was good. I think if it was longer with more numbers it might just be distracting and make it harder". (Simon)

Simon's description reinforced the principle of having the correct difficulty on the task, alluding to a longer span task becoming increasingly distracting. Interestingly, *Stephen* also began to describe a feeling of automacity in performing the football action, explaining the process as "not overthinking", which could indicate decreased use of cognitive processes during the action. The degree of consciousness of both WMT tasks and football tasks was a common theme in the interviews:

"Yeah it was like I was subconsciously holding them." (Stephen)

"I was, in subconscious, but not thinking about them as I was kicking the ball." (Stephen)

"about the number, but you have this moment where you don't think about it and you have to recall it." (Simon)

"It was definitely less conscious, you can't just remember the action, all the movements you didn't really have to focus on them too much." (Simon)

These descriptions, in addition to the earlier descriptions of *John*, begin to highlight how the participants processed the WMT tasks during the performance of football actions. This provides evidence of the participants holding tasks both with and without conscious reference (see explicit / cognitive relationship in Chapter 2), with additional description of reduced conscious processing of the football action itself. This could have demonstrated how WMT forced the participants to perform actions using implicit processes. Conversely, it could also demonstrate how participants were forced to store and retrieve the WMT tasks (in this case the span task), suggesting that the central executive needed to prioritise, and then resource differently, the concurrent tasks during action. In either case, these processes require the correct allocation of resources in working memory during action, a process which in itself requires working memory activation and manipulation of how information is stored and processed during the task.

Therefore, based on the interview transcripts, the experiences from Cycle 1 suggest that:

- Using WMT as a dual task was effective in making participants complete two concurrent tasks.
- Using WMT as a dual task had an impact on the action process during football exercises without affecting tactical or technical requirements of the exercise. Football actions remained applicable to their context.
- With the correct difficulty, WMT further affected how participants perceived the conscious and subconscious processing and execution of the tasks, with reference to automatic processing of both WMT tasks and football actions.
- Processing of the WMT and football action had an impact on the allocation of resources in working memory, which varied in degree and by the individual.

To conclude, the observations made in the interviews are a demonstration of how the literature described in Chapter 2, with its general principles surrounding working memory efficiency and activation, were experienced and described by participants during a real-world practice. This does not necessarily provide new theory, but rather it indicates that during Cycle 1 it was possible that a transfer from theory to practice took place within this research, which was a purpose of using PAR methodology.

5.2.2 Cycle 1 Reflection

This section reflects on the themes that emerged during the data collection, considering interview data and researcher observations that are relevant to the themes identified, but not directly associated with specific videos. To emphasize, no new themes will be identified in this reflection, rather, data inserted in this section will only reinforce or help discuss those themes already identified. This section categorizes the themes that emerged and gives a brief explanation of the implications for data collection Cycle 2, following into the next section where the planning for Cycle 2 is detailed.

Reflecting on Cycle 1, the following themes emerged through the triangulation of data, affecting the macro and micro systems of action:

1. Macrosystem - it is necessary to time WMT delivery at the beginning of the football action (perception) to overload working memory during the football action.
2. Macrosystem – When delivering WMT tasks verbally, it is easier to make the task delivery effective by focusing on one player with a specific action.
3. Macrosystem – Consistent volume and cadence are required when delivering WMT tasks verbally.
4. Microsystem - When determining whether the associated football action during WMT is successful or unsuccessful, the previous action from other players needs to be considered.
5. Microsystem – individualising the WMT difficulty correctly is more difficult when working with a large group.
6. Microsystem – Using WMT as a dual task was effective in making participants complete two concurrent tasks.

a. Microsystem – Using WMT as a dual task had an impact on the action process during football exercises without affecting tactical or technical requirements of the exercise. Football actions remained applicable to their context.
b. Microsystem – With the correct difficulty, WMT further affected how participants perceived the conscious and subconscious processing and execution of the tasks, with reference to automatic processing of both WMT tasks and football actions.
c. Microsystem – Processing of the WMT and football action had an impact on the allocation of resources in working memory, which varied in degree and by the individual.

The above themes were organized into three categories, informing the planning process for Cycle 2. The categories were "aural task delivery" (themes 1, 2 and 3), "WMT task effects" (themes 6, 6a and 6c) and "WMT difficulty prescription" (themes 4, 5 and 6b). Each category is summarised below, with implications for data collection Cycle 2 listed.

5.2.2.1 Category 1: Aural task delivery

Contributing themes:

1. Macrosystem - it is necessary to time WMT delivery at the beginning of the football action (perception) to overload working memory during the football action
2. Macrosystem – When delivering WMT tasks verbally, it is easier to make the task delivery effective by focusing on one player with a specific action
3. Macrosystem – Consistent volume and cadence are required when delivering WMT tasks verbally

The precise verbal delivery of WMT tasks is fundamental to using effective WMT within the Football Coaching session. Tasks need to be consistently delivered at the beginning of each action with a clear volume and cadence. In this session, the tasks were delivered verbally, and in windy conditions, this meant that the timing, volume and cadence required could only be achieved when working with an individual athlete – which was found to be easier in this training session. To work with an entire team there needs to be a solution that allows every individual to receive the task clearly. Wearable audio would prevent volume being an issue, whilst pre-recorded tasks would ensure that cadence would be consistent – this could also be achieved as the coach becomes more consistent in task delivery. One of the challenges in extending the training out to the entire team is that it will be difficult to time the tasks at the beginning of actions (in the perception stage of action) for all individuals. Instead, when working with the entire team, it may be more beneficial to use WMT tasks such as the N-back task, which are delivered in a constant stream (continuous delivery of N-back items throughout an exercise). Using a WMT task delivered in a constant stream would mean that not all actions would be overloaded at the precise time, however, it may be the first practically achievable way of training an entire team, as perception varies on an individual basis and would be difficult to consistently track. Should it be possible that the N-back task can be used with an entire team, the next issue would be getting individual answers back from the team and tracking the performance of each player to adjust difficulty correctly. Bearing in mind the issue of volume, as well as the ability of the coach to record the responses of each participant, there needs to be a way to simultaneously record the responses of all participants non-verbally.

To conclude, the implications of this category for the planning of Cycle 2 are:

- There needs to be an investigation into wearable audio for participants to ensure task volume is correct.
- Pre-recording tasks OR consistency in coach delivery will control cadence correctly.
- A constant stream WMT task, such as the N-back may make it possible to deliver WMT tasks to an entire team during play.
- A non-verbal, simultaneous response method for participants needs to be investigated to receive results from an entire team during play.

5.2.2.2 Category 2: WMT task effects

` Contributing themes:

6. Microsystem – Using WMT as a dual task was effective in making participants complete two concurrent tasks.

6a. Microsystem – Using WMT as a dual task had an impact on the action process during football exercises without affecting tactical or technical requirements of the exercise. Football actions remained applicable to their context.

6c. Microsystem – Processing of the WMT and football action had an impact on the allocation of resources in working memory, which varied in degree and by the individual.

Based on the interview data it appears that the impact of using WMT in the training session, in some way, replicated the impact of lab-based WMT from a processing point of view, validating the idea that methods documented in the WMT literature (see Chapter 2) could be applied in a "non-lab" context. Given that this is the first attempt using WMT in-context, this may be a start point showing that the issue of bringing lab-based training into the Football Coaching context may be possible. However, the precise impact of domain/task specific WMT cannot be investigated fully until the application methods (Category 1 and 3 here) are developed further.

To conclude, the implication for Cycle 2 is that there is merit in performing a second Cycle of PAR to develop the application methods of WMT, given that lab-based WMT impacts seem to be somewhat replicated in the football context. Refined application methods will allow more accurate validation of the merits of using WMT in the football context.

5.2.2.3 Category 3: WMT difficulty prescription

Contributing themes:

4. Microsystem - When determining whether the associated football action during WMT is successful or unsuccessful, the previous action from other players needs to be considered.
5. Microsystem – individualising the WMT difficulty correctly is more difficult when working with a large group.

6b. Microsystem – With the correct difficulty, WMT further affected how participants perceived the conscious and subconscious processing and execution of the tasks, with reference to automatic processing of both WMT tasks and football actions.

The impact of using WMT in the training session was elevated when the task difficulty was adjusted to match the ability of the participant, validating the use of adaptive training recommended in Chapter 2. However, the use of adaptive training presents two challenges in the application of WMT to the football context. First, that when measuring the success of an action, the quality of a previous action by a team mate may have an influence on whether an action is executed successfully or not. Therefore it needs to be considered when prescribing WMT difficulty based on the success of football actions. The second challenge is that individualising the difficulty is currently possible when working with the individual, but much more complex to apply when delivering tasks to an entire team. Therefore, a method of sending individually adapted WMT tasks to participants within the group setting needs to be investigated.

This category has the following implications for Cycle 2:

- Adaptive training difficulty needs to be applied where possible, therefore the success rate of participants needs to be recorded during training, with external factors that directly influence success being considered.
- It is necessary to investigate how individually adapted tasks could be sent to each participant within a group setting, with individual responses also recorded to adapt the WMT difficulty level for each participant.

In conclusion, based on the reflection of Cycle 1, the following are implications that guide the planning process for Cycle 2:

Category 1 – Aural delivery

- There needs to be an investigation into wearable audio for participants to ensure task volume is correct.
- Pre-recording tasks OR consistency in coach delivery will control cadence correctly.
- A constant stream WMT task, such as the N-back, may make it possible to deliver WMT tasks to an entire team during play.

- A non-verbal, simultaneous response method for participants needs to be investigated to receive results from an entire team during play.

Category 2 – WMT task effects

- The impact of lab-based WMT seems to be somewhat replicated by WMT use in the football context.
- Refined application methods will allow more accurate validation of the merits of using WMT in the football context.

Category 3 - WMT difficulty prescription

- Adaptive training difficulty needs to be applied where possible, therefore the success rate of participants needs to be recorded during training, with external factors that directly influence success (e.g. the quality of a team mates' action) being considered.
- It is necessary to investigate how individually adapted tasks could be sent to each participant within a group setting, with individual responses also recorded to adapt the WMT difficulty level for each participant.
- The following section details the planning of Cycle 2, including implications from Cycle 1 that can/will be investigated, and which implications need to be investigated later in the research process.

5.2.3 Planning Cycle 2

Cycle 2 progressed the application of WMT to football training by extending the WMT volume to 30 minutes of training, therefore including the Positioning Game as an exercise where

WMT would be used. Cycle 2 was also required to address the following implications from Cycle 1:

- A constant stream WMT task, such as the N-back, may make it possible to deliver WMT tasks to an entire team during play.
- A non-verbal, simultaneous response method for participants needs to be investigated to receive results from an entire team during play.
- Pre-recording tasks OR consistency in coach delivery will control cadence correctly.

These implications were addressed by the following (respectively)

- The creation of a list of N-back trials was created for the coach to use during the session.
- Use of a Classroom Response System (CRS) to allow a non-verbal response to WMT tasks from participants during play.
- A discussion with the coach to establish controlled cadence and volume when delivering tasks.

The following implications from Cycle 1 were set aside to be addressed either in later cycles or outside of this research:

- It is necessary to investigate how individually adapted tasks could be sent to each participant within a group setting, with individual responses also recorded to adapt the WMT difficulty level for each participant. *Addressed in part (response only) in Cycle 3

- There needs to be an investigation into the use of wearable audio for participants to ensure task volume is appropriate. *addressed by research into wireless audio technology / bone conduction technology – see section 5.4.3
- Adaptive training difficulty needs to be applied where possible, therefore the success rate of participants needs to be recorded during training, with external factors that directly influence success (e.g. the quality of a team mates' action) being considered.

5.3 Cycle 2

5.3.1 Training session 2

The process of planning action for Cycle 2 considered the findings and implications of Cycle 1. In practical terms, this meant the following:

- Thirty minutes of training was delivered as a representation of a realistic dose of WMT in a session, considering that participants would have begun to adapt to and accept the use of, WMT.
- The WMT was applied to player actions and team/player tasks completed in the Positioning Game, with the coach delivering WMT whenever the exercise was "live".
- The creation of a list of N-back trials ranging in difficulty from 2-back to 4-back was provided for the coach to use during the session. The trials were read out individually, not in a constant stream – this was done so that the ability to gain a response from athletes could be tested during the session.
- A Classroom Response System (CRS) was used to allow a non-verbal response to WMT tasks from participants during play. The participants were instructed to press "A" when they heard a matching N-back item, or "B" if they did not recognize a matching N-back item.
- The coach practiced and was able to execute the verbal delivery of N-back tasks with a consistent volume and cadence.

5.3.1.1 Theme – Macrosystem - Delivering the N-back meant the coach was unable to give "on the run" feedback during play. Therefore, using WMT in this way would negatively impact the coaching process

Video 5.7 2 back #7

Coding – Mid action, Unsuccessful FA, Remote Successful

Researcher notes – play broke down prior to the WMT task. An increased number of responses… but the signal distance of the CRS units meant some responses weren't received.

Additional videos: 2-back #2

Coding – Mid action, Remote unsuccessful, Successful FA

Researcher notes – No correct responses, coaching/player communication and/or receiver/remote communication a factor?

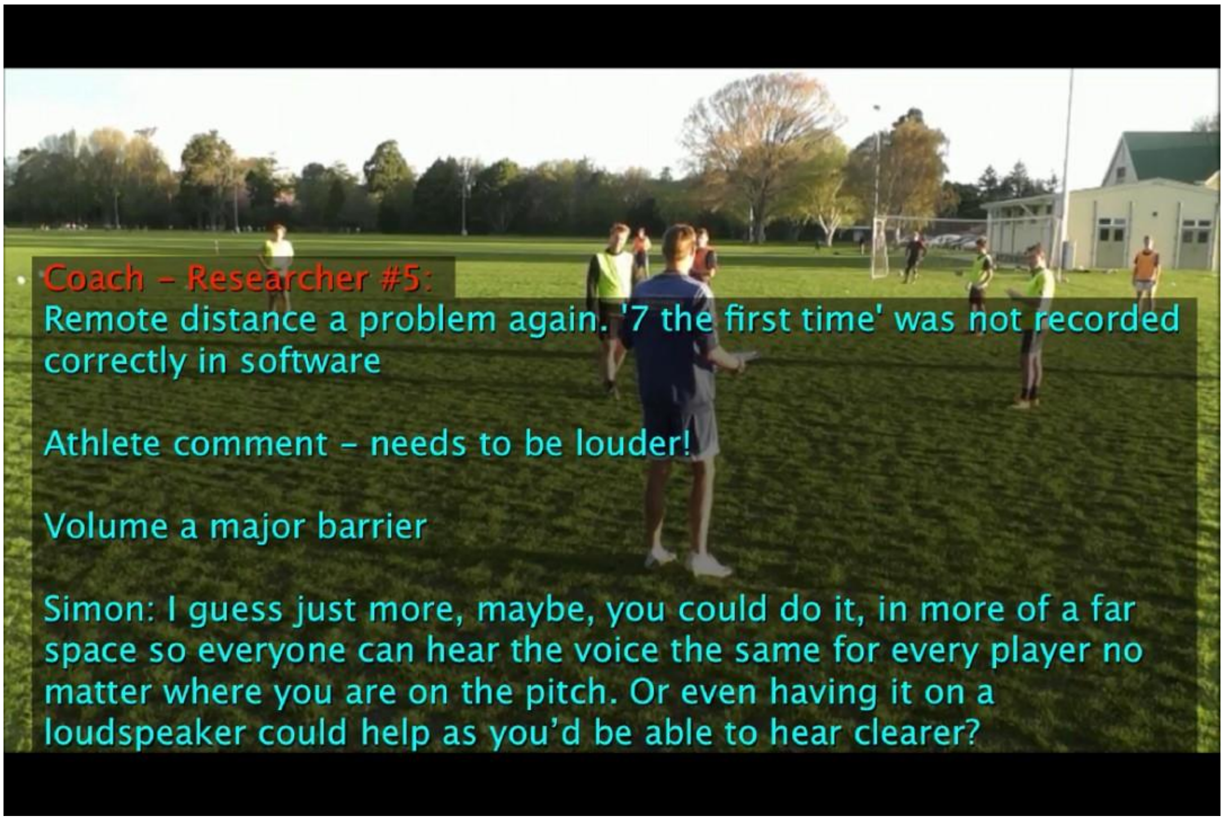
Description and Analysis

Video 5.7 demonstrates the disruptive impact of coach-led WMT during the training session. Due to the WMT, the coach looks down to call out the N-back trial to the players. During this moment there are two themes at play; the first theme is related to the problems associated with using a verbal task delivery, covered in detail later as Theme 5.3.1.3; the second theme (Theme 5.3.1.1) is detailed here. The play continues until mid-way through the N-back trial, with the players appearing to be lost in the game until the ball leaves play. The coach, who is looking down to read the N-back trial, does not see that the ball has gone out of play. This demonstrates that using coach-led WMT can limit the attention a coach can give to the coaching process, in this case, coach-led WMT prevented the enforcement of exercise constraints and explicit feedback. The consequence is two-fold – firstly, the fact that the trial continues once the ball has left play can limit the perception of the players that WMT is relevant to the football actions being performed. The game stops because the ball leaves the field of play, but the WMT task continues, meaning that the use of WMT does not occur in reference to the objective conditions of the game and is therefore irrelevant and not domain-specific. The second consequence is that the coach is not able to apply the coaching process whilst delivering additional WMT – therefore supporting the perception that from a coaching perspective, WMT may not be applicable in the training session.

Despite these problems, Video 5.7 helpfully demonstrates that the responsibility of delivering WMT needs to be fulfilled by a process separate to the coach, and that WMT should only be carried out whilst the ball is in play. Therefore, this theme carries the implication that non-coach-led methods of delivering WMT need to be explored, as well as ensuring that WMT task trials are only delivered when the game is live. Solving these two problems may help mitigate the negative impact of WMT on the coaching process that was demonstrated in this training session.

5.3.1.2 Theme – Macrosystem - Remote response allowed more participants to respond… but was limited by the response method, signal range of the CRS system and a lack of individualization

Video 5.8 Coach Researcher #5



Coding – Mid Action, Remote unsuccessful, Successful FA

Researcher notes – Remote distance a problem again, answers not recorded correctly in software. Athlete comment on volume, need to be loud in task delivery.

Interview – Simon: "I guess just more, maybe, you could do it, in more of a far space so everyone can hear the voice the same for every player no matter where you are on the pitch. Or even having it on a loudspeaker could help as you'd be able to hear clearer?"

Additional videos: Coach Researcher #8

Coding – NA

Labels – NA

Researcher notes – solving the distance issue by walking closer to the play with the receiver

Description and Analysis

Video 5.8 demonstrates two themes, the first being Theme 5.3.1.3 (detailed in the next video) relating to the use of verbal task delivery at the very beginning of the video, the second being this Theme (5.3.1.2), relating to the issues found when using the CRS system. It also demonstrates both the difficulty and importance of coach-researcher interaction in the PAR methodology.

The first issue highlighted in Video 5.8 is the method of response that the participants had to use. In this session there were two responses that the participants could give using the hand-held remote during an N-back trial – button 1 indicated that they had recognised a correctly matching N-back item, whilst button 2 indicated that they did not recognize a matching N-back number. Video 5.8 shows the action following one of the tasks, from which a second problem arose, during the action not all answers to the trial were received (neither button 1 or 2) despite the participants pressing the button of their choice (this was later solved by the researcher moving with the play to keep the CRS remotes in range of the receiver). This could only be recognised by asking which participants had attempted to respond – which represented the third problem, that we would receive responses but not know who the response was from – which could create difficulty in delivering adaptive training in the future. In addition, during the interviews participants explained that they would often forget they were holding the remote during play.

> "I guess it was harder, like you were playing but maybe pushing the wrong button, when you are not concentrating you will just push any button and push the wrong one, and you might get it right even though you are wrong. I pushed the wrong button." (Stephen)

Furthermore, pressing the correct button requires an additional motor task on top of the football action itself, therefore it can be argued that the use of a remote system made the training non-specific to football, and therefore not representative of best coaching practice.

> "I don't think it affects it as much as the calling out did, because you can, you're not using your hands anyway, *so you can think about what you are doing with your hands and feet separately." (Simon)*

The conclude, Theme 5.3.1.2 carries the following implications:

- The use of a binary answering system did not allow us to recognise that participants may not have received the task correctly.

- Any remote response system used needs to have a range more suited to large playing areas to be practical. Wireless technology may solve the range issue and needs to be investigated.
- Individual response profiles are required to recognise and diagnose response issues for participants whilst also allowing the system to track task success for each individual.
- The use of a handheld remote to complete the N-back trial is unlikely to be a long-term solution to collecting non-verbal responses to WMT trials. A response solution that does not require further motor tasks is desirable.

*5.3.1.3 Theme – Macrosystem - **Consistent audio that reaches all participants at the same time would improve the training***

Video 5.9 2 back #2

Coding – Mid action, Remote unsuccessful, Successful FA

Researcher notes – No correct responses – coaching/player communication and/or receiver/remote communication a factor?

Additional videos: 2-back #11

Coding – Mid action, Successful FA, Remote successful, Remote unsuccessful

Labels – NA

Researcher notes – distance may have limited responses; the play was not disrupted so participants may not have heard the task

Interview –

Simon: "I guess just more, maybe, you could do it, in more of a far space so everyone can hear the voice the same for every player no matter where you are on the pitch."

Description and Analysis

Video 5.9 demonstrates the issues in verbal task delivery observed during the training session. It was unclear in this instance whether it was a remote failure or communication failure, but this was found during the interviews to be the latter. The same issue is demonstrated in Videos 5.7 and 5.8. Briefly, the use of WMT could be pointless if the participant is unable to hear the tasks clearly and consistently during the training session.

> "…sometimes I wouldn't even hear the numbers. That was partially because I was at the other end of the field" (Simon)

In Cycle 1, this was solved by using the Digit Span for one player during the Passing Practice, however, the goal of this training session was to explore the use of WMT during the Positioning Game with every participant, where more dynamic tasks are required. Verbal delivery of WMT does not appear to be suitable for use in the context of the Positioning Game if the goal is to deliver a task to all players involved.

> "Once it moved into a bigger on both before and during the N-back, he was shouting to the whole team and was standing from further away. So the whole team had to listen and it probably dropped the quality of the training because everyone was

thinking about… the whole delivery of the numbers back, whereas in the first part it was one player doing a simple thing and then returning numbers. So, it got harder." (John)

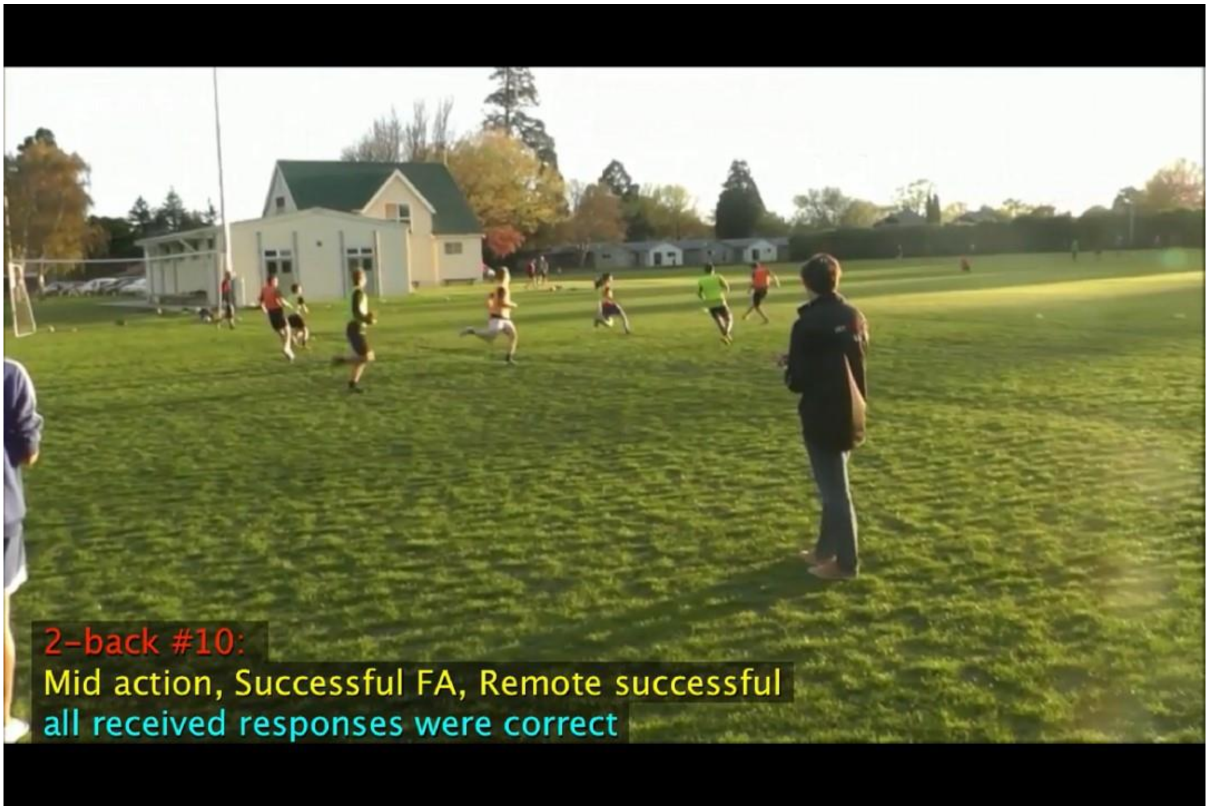
Some suggestions were made by the participants during the interviews relating to this – that an automated system could ensure each task had the same cadence and tone, whilst a loudspeaker could ensure that volume was suitable for all participants.

> "In some parts, the way the numbers are said could put someone off, so if you could have a computer-generated number talker… that makes it clear what the numbers were, with them all pronounced the same, tone the same… so everyone can hear the voice the same for every player no matter where you are on the pitch. Or even having it on a loudspeaker could help as you'd be able to hear clearer?" (Simon)

Based on the analysis of Theme 5.3.1.3 it appears that the use of automated task delivery and audio tech needs to be explored. Regarding audio – a clear issue is that the use of loudspeaker could make WMT impractical in certain situations (e.g. interfering with explicit coach feedback), therefore personal audio (headphone technology) would be a preferred course of investigation.

5.3.1.4 Theme – Macrosystem – Applying WMT in the Positioning Game when many novel actions are required (with increased match realism) is significantly more challenging than using WMT during player actions in the Passing Practice – need to consider the exercise complexity/familiarity relative to the players

Video 5.10 2 back #10



Coding – Mid action, Successful FA, Remote successful

Researcher notes – all received responses were correct

Additional videos: 2 back #7

Coding – Mid action, Unsuccessful FA, Remote Successful

Researcher notes – play broke down prior to the WMT task. An increased number of responses… but the signal distance of the CRS units meant some responses weren't received.

Description and Analysis

Video 5.10 demonstrates the increased speed, complexity and unpredictability of football actions occurring in the Positioning Game when compared to a Passing Practice, due to the increased game resistance caused by having a direct opponent.

> "…a lot of variables came into play really, whereas there aren't any variables when kicking a ball to the same player every time." (John)
>
> "…the second part, I think was much better, because we could do whatever we wanted, pass to whoever we wanted to or run it, rather than just passing to a select player." (Simon)

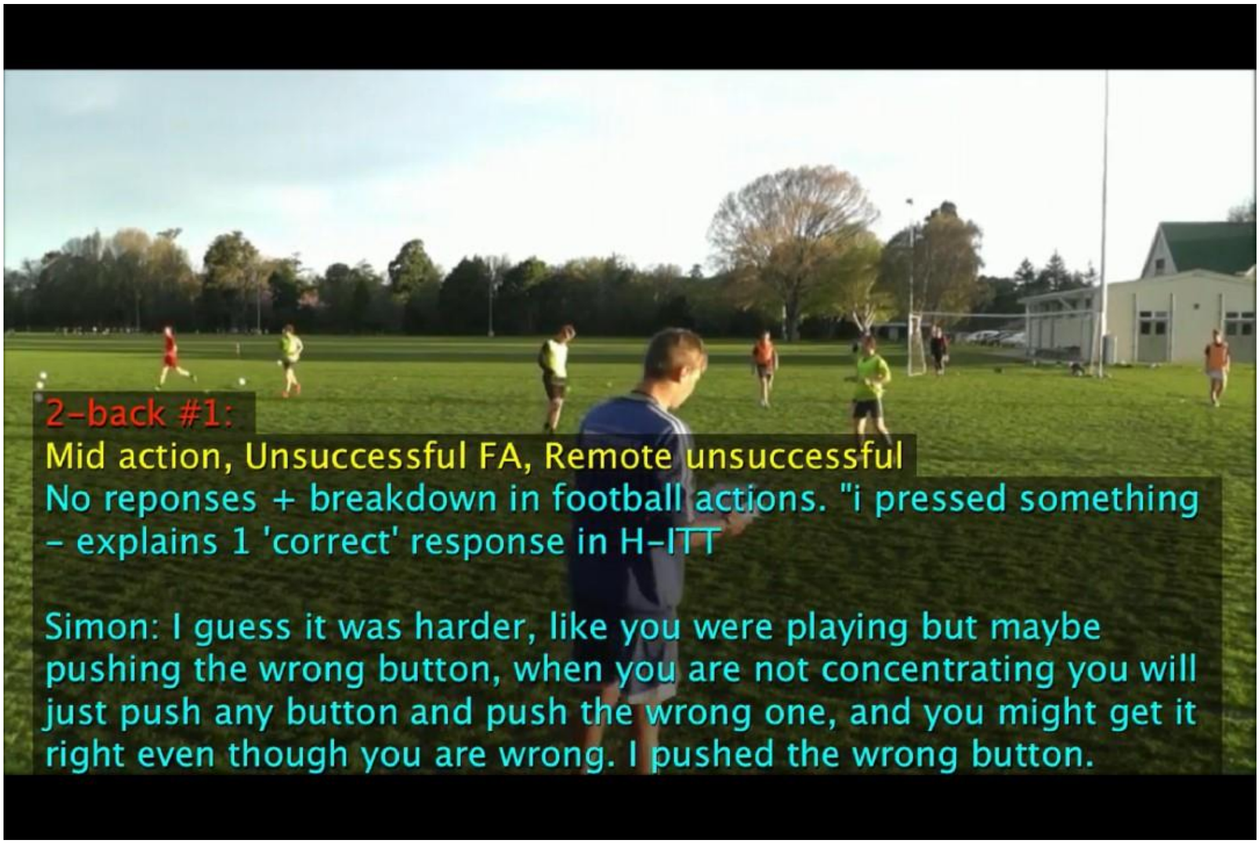
Therefore, two issues with integrating WMT may be considered. First, that participants can benefit from being familiar with the rules and actions required by an exercise prior to the introduction of WMT (which also applies to coaches – who need to see that the actions that they wish to develop are present in the exercise prior to using WMT). Second, that the difficulty transfer of WMT from the Passing Practice to the Positioning Game may need to be adjusted relative to the increase in game resistance for each player – i.e. as the actions are more complex, the WMT difficulty may need to be lowered in response. This was supported in the participant interviews;

"Yeah when the activity got harder I put less attention to listening and remembering the question. I think if the activity was really basic, passing or something, I would have been able to process the numbers more easily, it's just, yeah, it was just that level of difficulty of the activity." (Stephen)

"I saw people struggling, particularly towards the end when the remotes were brought in." (John)

5.3.1.5 Theme – Microsystem - Familiarity with the tasks allowed training to be delivered more effectively

Video 5.11 2 back #1



Coding – Mid action, Remote unsuccessful, Unsuccessful FA

Researcher notes – No responses in addition to a breakdown in football actions. Participants not understanding the task – hence the facetious response "I pressed something".

Interview-

Simon: "I guess it was harder, like you were playing but maybe pushing the wrong button, when you are not concentrating you will just push any button and push the wrong one, and you might get it right even though you are wrong. I pushed the wrong button."

Additional videos: 2 back #10

Coding – Mid action, Successful FA, Remote successful

Researcher notes – all received responses were correct

Description and Analysis

Video 5.11 is an example that occurred early in the session before participants became familiar with the exercise and tasks. Participants were confused by what they had been asked to do, and therefore any results gained from the task (whether football or WMT related) would not be relevant to prescribing adaptive WMT.

> "…but if the players had the opportunity to use the remotes and have a refresher on what the N-back was. That could have helped, not necessarily the numbers they produced, but to take away a factor that wasn't important, which was the use of the remote, because if we were all about the numbers, it would have helped to take that process away. (John)
>
> 'So there is an adaptation to the methods where people are adjusting to the fact the tasks were there?" (Researcher)
>
> "Yeah exactly." (John)

In addition, it would have been unclear to the coach whether the actions he intended to develop were being used in the exercise he had designed. In Video 5.11 participants were able to give correct responses despite a difficult, but relevant, series of actions in the exercise. Therefore, the introduction of WMT may be suited to being delivered at the end of a form of a checklist, where it is first clear that the participants can understand and execute the tasks and actions required to complete the exercise and can be subsequently overloaded via the introduction of adaptive WMT.

5.3.1.6 Theme – Microsystem - The N-back was found to be very challenging from 3-back and above compared to Digit Span use… but may have been due to limited adaptation **opportunity**

As found in Cycle 1, themes that affected the microsystem of action are not always observable in video, and instead are triangulated based on participant observation, researcher observation and/or theory. This theme emerged from the participant interviews, where comments were regarding the change from working with a Digit Span WMT task to the N-back WMT task.

> "I found it pretty challenging, yeah, it was hard to focus on your own game and try to talk to everyone else, because you are talking and listening. And just, especially with the different numbers, doing the 2-back and the 3-back, that was harder than remembering a chain of numbers I think. Because you processed it rather than just remembering. (Simon)

Not only was the N-back perceived to be more difficult by the participants, but the change in difficulty between performing a 2-back task and a 3-back task was also highlighted –

> "… when we got live feedback when we went through, there were more responses on the 2-back than the 3-back, did you find you were able to respond to most of the 2-back?" (Researcher)
>
> "Yeah it was fairly obvious, you could hear it very clearly." (Simon)

This shows the N-back may be a less difficulty-sensitive task in its early levels when compared with the Digit Span task used in the Passing Practice and the previous training session. Based on the participant interviews, this could be because the 2-back requires minimal recall – which means it could be useful for acclimatising participants to using WMT during the Positioning Game before advancing difficulty to overload working memory.

> “It’s quite a big jump between the two and three isn’t it?” (Researcher)
>
> “Yeah with the 3 you have to stop and think about it, try and remember the numbers.” (Stephen)

The need to acclimatise the participants and let the participants become familiar with the WMT before advancing the difficulty was also apparent in both video footage and the interviews, despite it seeming (in the short term) a practical solution for that stage of the research.

> “Yeah, I think it was reasonably well done, probably couldn’t have done it much simpler. I sort of just forgot about the remote though, wouldn’t press any buttons, forgot it was in my hand.” (Simon)
>
> “It was definitely harder …......partially because I wouldn’t switch on and just forget about it.” (Stephen)

Simon and *Stephen* twice make the point that they would forget about the remote in their hand during play, despite comments that it seemed a simple solution for using WMT in the training session. This demonstrates that whilst using a remote to gather responses from a larger number of participants seemed practical, in action, it was not an ideal solution. Two factors played a part in this case. The first factor was the limited time for the participants to adjust to using the remotes, which needed to be demonstrated prior to the start of the session –

> "…but if the players had the opportunity to use the remotes and have a refresher on what the N-back was. That could have helped, not necessarily the numbers they produced, but to take away a factor that wasn't important, which was the use of the remote." (*Wayne*)

The second factor was that the use of the remotes introduced an additional non-specific motor task to playing the game (detailed in Theme 5.3.1.2), and as such, the participants would have to be given time to practice and use that motor task in addition to playing the game. From a coaching perspective, this raises questions surrounding the relevance and specificity of learning a concurrent motor task that doesn't relate to playing football itself.

In summary:

- The difficulty increase between the 2-back and 3-back tasks needs to be considered when prescribing WMT to participants. The 2-back may be better used to acclimatise participants to complete WMT tasks during play than as a task used to induce overload, as participants perceived a marked difference in internal processes when dealing with the 3-back task.

- The CRS created the opportunity to test sending and receiving WMT tasks and solutions to a larger group of athletes in a game related exercise. However, because the remotes introduce a non-specific motor task to the football actions required, a solution that allows a response to be given without requiring an additional motor task could be better suited.

5.3.2 Reflection

This section reflects on the themes that emerged during Cycle 2, considering interview data and researcher observations that are relevant to the themes identified, but not directly associated with specific video clips. As in the Cycle 1 reflection, no new themes will be identified, rather, data inserted in this section will only reinforce or help discuss those themes already identified. This section categorizes the themes that emerged and gives a brief explanation of the implications for data collection Cycle 3, following into the next section where the planning for Cycle 3 is detailed.

Reflecting on Cycle 2, the following themes emerged through the triangulation of data, affecting the macro and micro systems of action:

1. Macrosystem - Delivering the N-back meant the coach was unable to give "on the run" feedback during play. Therefore, using WMT in this way would negatively impact the coaching process.
2. Macrosystem - Remote response allowed more participants to respond… but was limited by the response method, signal range of the CRS system and a lack of individualisation.
3. Macrosystem - Consistent audio that reaches all participants at the same time would improve the training.
4. Macrosystem - Applying WMT in the Positioning Game where novel actions are required (with increased match realism/resistance) is significantly more challenging than using WMT during player actions in the Passing Practice – need to consider exercise complexity/familiarity.
5. Familiarity with the tasks allowed training to be delivered more effectively.

6. The N-back was found to be very challenging from 3-back and above compared to Digit Span use… but may have been due to limited adaptation opportunity.

The above themes were organized into two categories, informing the planning process for Cycle 2. The categories were "The negative impact of coach-led WMT on the coaching process" (themes 1, 4, 5) and "Developing task delivery and response" (themes 2, 3, 6). Each category is summarised below, with implications for data collection Cycle 3 listed.

5.3.2.1 Category 4: The negative impact of coach-led WMT on the coaching process

Contributing themes

1. Macrosystem - Delivering the N-back meant the coach was unable to give "on the run" feedback during play. Therefore, using WMT in this way would negatively impact the coaching process.
1. Macrosystem - Applying WMT in the Positioning Game when many novel actions are required (with increased match realism/resistance) is significantly more challenging than using WMT during player actions in the Passing Practice – need to consider exercise complexity/familiarity.
2. Familiarity with the tasks allowed training to be delivered more effectively.

The impact of coach-led WMT on the coaching process was apparent throughout the training session, limiting observation and feedback opportunities for the coach whilst simultaneously affecting the organisation and exercise understanding of the participants. Having the coach deliver the WMT tasks was appropriate in the short term to introduce the use of WMT in Football Coaching, however, following this session it is apparent that coach-led delivery is not suitable for the long-term integration of WMT into Football Coaching, due to the attentional demands placed on the coach when delivering the tasks. Often the coach did not see a stoppage in play or a mistake in the exercise, meaning that he was unable to influence the participants. This means that the basic responsibilities of the coach cannot be fulfilled, and therefore this would not be an acceptable solution in the field for the long term. A solution could be to get additional coaching staff to deliver WMT, however in this context that alternative was/is not possible. In any case, Category 5 explains the shortfall of verbal task delivery and offers the potential for automated solutions, rendering the use of additional staff members pointless.

Compared to the Passing Practice, the game resistance and subsequent action demands involved in the Positioning Game were far more demanding. In this case, WMT could not be adjusted in relative to the demands of the exercise (as the N-back was introduced instead of the continued use of the Digit Span task) and appeared to have a significant negative impact on the actions of the participants. In future sessions, WMT would need to be adjusted relative to the game resistances of the exercise and relative to the individual participant. To prescribe WMT correctly between different exercises the ability of the participant to execute the football actions required by the exercise need to be considered. Distinguishing between unopposed, interference, semi-opposed and opposed game resistances could be a relevant start point, with subsequent exercise constraints such as the area size or rules also considered. This therefore demands a logical progression in exercise design within the long-term planning of Football Coaching, for which the periodisation of WMT may aid coaches to distinguish exercises between developing their team and players (for which WMT would be relevant) versus making novel adjustments for an upcoming opponent.

Finally, in the session it was apparent that there was a lengthy adjustment period to using the WMT tasks in the Positioning Game via the CSR system. Within the context of this research, this is both necessary and expected – the purpose is to use the adaptation period to understand the pros and cons of the training method. However, in a long-term context, this session has demonstrated the need to introduce WMT to the coaching environment both slowly and carefully, with a clear induction needed for participants. The adjustment period required in the future may depend on the method of delivering WMT, which is discussed in the following category. In any case, the disruption caused by introducing WMT in the Positioning Game would not be acceptable in normal practice, so both delivery and adaptation need to be improved.

In summary, the outcomes of Category 4 (“The negative impact of coach-led WMT on the coaching process”) are:

- Automated delivery of WMT is preferable to coach-led delivery
- WMT prescription needs to account for the game resistances (opposition, playing area, rules etc.) of an exercise relative to the level of the individual, which also means the coach must have an awareness of how exercises and actions will be progressed logically throughout a competitive season.
- A pre-training induction to WMT is required to speed up the adaptation of participants in using WMT. The length and detail of induction and subsequent adaptation will depend on the future delivery methods of WMT, discussed in the following category.

5.3.2.2 Category 5: Developing task delivery and response

Contributing themes

2. Macrosystem - Remote response allowed more participants to respond… but was limited by the response method, signal range of the CRS system and a lack of individualization
3. Macrosystem - Consistent audio that reaches all participants at the same time would improve the training
3. The N-back was found to be very challenging from 3-back and above compared to Digit Span use… but may have been due to limited adaptation opportunity

The methods of delivering WMT in this training session both advanced the integration of WMT into Football Coaching and highlighted the pitfalls that currently exist and need to be solved. The use of the CRS allowed the initial testing of whether WMT could be used with multiple participants at the same time. The method was successful in allowing multiple participants to respond to the tasks, however, this success was limited due to several problems:

- The use of a handheld remote introduced a secondary, non-specific motor task to the exercise, with participants often forgetting to use the remote or pressing the wrong button by mistake.
- The limited signal range of the CRS meant that some responses weren’t recorded, forcing the researcher to move closer to the play.
- A lack of individualised response profiles meant that individual results could not be recorded, and response problems were subsequently difficult to address.

To advance the use of WMT with groups of participants in the Positioning Game towards a practical method, the three problems above need to be addressed. First, by finding a way of allowing participants to respond to WMT tasks without the use of a secondary motor task. Second, by using a more advanced form of signal for the responses, such as a wireless or cellular connection, which theoretically would allow a greater range to the infrared technology use by the CRS. Third, individual response profiles for each participant need to be created, the CRS system has this capability, which can be incorporated into the planning for Cycle 3.

In addition to the drawbacks found with using the CRS, participants highlighted the need for improving the verbal delivery of the WMT tasks during play, which was not always clear and may be a contributing factor to incorrect or non-response to the WMT tasks. Suggestions of a loudspeaker appear impractical, as this would interfere with the ability of the coach to provide feedback. Therefore, as mentioned in section 5.2.3, there needs to be an investigation into the use wearable audio for participants to ensure task volume is appropriate, with both wireless and bone conduction audio possible options (discussed in section 5.6).

Finally, it was apparent that care needs to be taken in the introduction of new WMT methods to participants, as there is a significant adjustment to both the method of task delivery and the difficulty of new tasks, especially when used in the Positioning Game exercises. In future, it would be beneficial to give participants an introduction prior to the training session taking place, as noted in Category 4.

In summary, the implications of Category 5 (“Developing task delivery and response”) on the planning of both Cycle 3 and future research are:

- A response method that does not require a secondary motor task needs to be investigated.
- An alternative signal to infrared (such as wireless or cellular) needs to be used to transmit responses over a greater distance.
- Individual response profiles need to be set up for the CRS.
- The use of wearable audio for the participants needs to be incorporated.

Overall, it seems that using a non-verbal remote response system during play may be a preferred option for using WMT, provided the tasks can be automated in delivery, audio controlled for each player, requiring a response that doesn’t need a secondary motor task, and with individual results recorded over a greater distance range. Unfortunately, it is possible that the hardware/software required to address all of these problems may not be in existence at this point, this position on technology will be covered in Section 5.4.3.

5.3.3 Planning Cycle 3

Cycle 3 progressed the application of WMT to football training by extending the WMT volume to 45 minutes of training, therefore including the “Game Training” as an exercise where WMT would be used. Cycle 3 was also required to address the following implications from Cycle 2:

- WMT prescription that considers the exercise complexity for each individual, whilst coaches need to have a logical hierarchy of progressions in their training sessions.
- Individual response profiles for the CRS.
- A pre-training induction to WMT to reduce the in-session adaptation period.

- These implications were addressed in Cycle 3 by (respectively):
- Adjusting the exercise progression to include the introduction of WMT as a logical step in the progression of the exercises – specifically the Game Training element.
- Setting up individual response profiles for the CRS, with remotes assigned to specific participants.
- A pre-training demo of the CRS.

The following implications were set aside for investigation following Cycle 3, and are detailed in section 5.4.3.1 (Technology that could improve the delivery of WMT):

- Automated delivery of WMT.
- The use of wearable audio for the participants.
- A response method that does not require a secondary motor task.
- An alternative signal to infrared (such as wireless or cellular).

5.4 Cycle 3

The process of planning action for Cycle 3 considered the findings and implications from Cycle 2. In practical terms, this meant the following:

- Individual profiles set up for the CRS system, allowing the tracking of individual results.
- A pre-training demo of the CRS to minimise the time required for familiarisation.
- Forty-five minutes of coach-led WMT was delivered during the training session, representing the WMT volume that would be delivered with participants who are relatively familiar with WMT.
- WMT was applied to player actions in the Passing Practice, team and player tasks in the Positioning Game, and team and player tasks in the Game Training.
- The N-back task was used as a starting trigger for the Game Training exercise (which focused on set piece play), introduced as part of a logical exercise progression with the intention of providing a more accurate overload of football actions using WMT than observed in Cycle 2. The coach utilised a problem-solving pedagogy for this exercise, changing his role in providing feedback whilst delivering coach-led WMT.
- Due to the timing of Cycle 3 coinciding with both a competitive tournament and the adjournment of the team, participants were not available for interview following Cycle 3. Therefore, this section is triangulated based on researcher notes following video analysis of the training session, video observation and researcher comments during the video session.

5.4.1 Training session 3

5.4.1.1 - Macrosystem - It was possible to use the N-back task during exercises that utilized a problem-solving pedagogy with reduced interference on the structure of the exercise

Video 5.12 2-back #5

Coding - Pre action, Successful FA, Remote Successful

Researcher notes: First example of successful FA + Remote response. Players showing new solutions within the exercise as part of a problem-solving approach.

Additional Videos - 3-back #1

Coding - Pre action, Unsuccessful FA, Remote successful

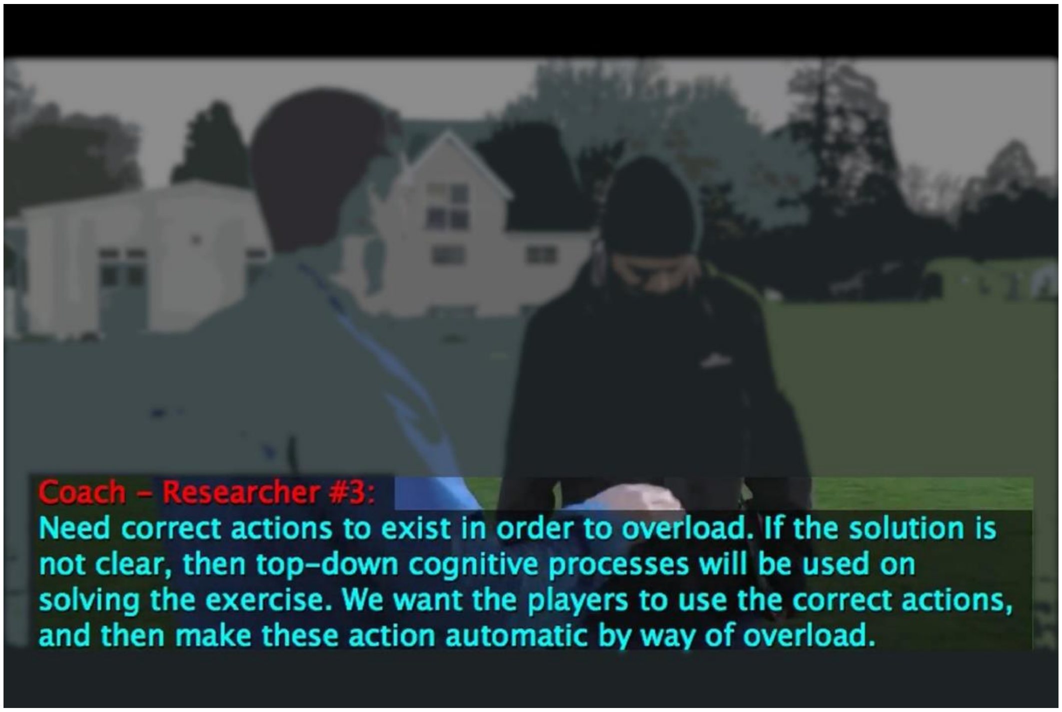
Researcher notes - Successful N-back task, with participants demonstrating their understanding of the WMT tasks. (Referring to changes in difficulty)

Description and Analysis

Video 5.12 showed the players participating in a problem-solving exercise involving set piece training and presenting a new solution to the situation created by the coach. The play started as the WMT task was verbally delivered from the coach and ended with both a goal attempt and successful remote response to the N-back task. The problem-solving pedagogy in use here empowers athletes to solve a situation with little guidance, which meant the coach did not need to give feedback during the exercise, allowing him to deliver the WMT tasks without compromising his pedagogical approach. This method of using WMT in the session caused less interference than previous sessions, allowing the coach to give feedback in-between sequences of play. However, the coach is still distracted to a degree during the action, so he needs to observe the action carefully whilst giving the WMT task to be able to give appropriate feedback or reinforce the organization of the exercise after the sequence of play. The use of the remote system assisted in reducing interference in the pedagogical approach, as the coach did not need to deal with the responses to the task. A future step would be to eliminate the need for the coach to deliver the task verbally, virtually removing his involvement in the delivery of WMT, allowing full attention to be dedicated to the pedagogical approach only.

5.4.1.2 - Macrosystem - Using WMT before players understood a task clearly meant that incorrect actions were performed and subsequently overloaded – which defeated the purpose, changed through dialogue between coach and researcher

Video 5.13 Coach-Researcher #3



Coding: N/A

Researcher notes - Need correct actions to exist in order to overload. If the solution is not clear, then top-down cognitive processes will be used to solve the exercise. We want the players to use the correct actions, then make these actions automatic by way of overload

Additional Videos -

Researcher Comments #7

Coding: N/A

Researcher notes - using WMT before a solution is pointless… why would an athlete consider WMT useful if they haven't solved the exercise yet?

2-back#1

Coding - Pre action, Unsuccessful FA, Verbal unsuccessful, Remote Unsuccessful

Researcher notes: Participants were unclear what the task was – needed to check understanding... another instance where a player forgot to use the remote.

Description and Analysis

Video demonstrates the power of using PAR as a methodology in this instance. The researcher and coach are able to collaborate and change practice during the session. During this part of the training session, the coach was using a problem-solving methodology to develop the team and players tasks involved in set piece play. *Wayne* started to use WMT before the players were demonstrating a consistent set of behaviours within the exercise. The impact of this was that the players were not completing the working memory tasks whilst performing successful football actions. This is likely due to not having identified the actions that would provide a consistent solution to the exercise. Therefore, working memory was fully occupied by the problem-solving process – they were still choosing a solution, as opposed to practicing one.

In this scenario, the use of WMT needs to be delayed until a solution becomes apparent and the player actions are repeatable. By applying WMT after the solution is identified we can force the actions to be completed with a greater degree of implicit/procedural knowledge, therefore freeing up activation for new solutions that can be tested in a subsequent scenario. In sum, creating greater domain-specific efficiency that then allows activation to be used for a wider range of solutions. This process could be cyclical, allowing solutions to be systematically made procedural whilst also training working memory to handle more solutions to progressively complex situations introduced by the coach. This may impact the prescription of WMT volume, indicating that a mastery approach, not a time approach, may be more effective in some cases.

5.4.1.3 - Macrosystem - Using N-back as a start trigger meant that the entire sequence of play could be completed with a WMT load

Video 5.14 Researcher Notes #1

Coding - Pre action, Unsuccessful FA, Remote successful

Researcher notes: Remote response on previous action was a mistake. Remote response successful, demonstration of an opportunity to deliver a second N-back trial during the action, therefore creating a constant-stream WMT task during the play.

Additional Videos -

2-back#5

Coding - Pre action, Successful FA, Remote Successful

Researcher notes - First example of successful FA + remote response. Players showing new solutions within the exercise as part of a problem-solving approach.

2-back #9

Coding: Pre-action, Unsuccessful FA, Remote successful

Researcher notes: Example of a participants being able to complete the sequence of play whilst answering the 2-back correctly, despite the limited time constraint involved in the play (a corner kick).

Description and Analysis

Video 5.14 demonstrates both the usefulness of using WMT as a start trigger to overload actions, but also that a second task could be delivered in the same sequence to overload subsequent actions. This relates back to theme 5.2.1.6, where *John* was playing as a goalkeeper and attempted to complete a second football action whilst still solving the WMT from the first action. Based on this video, it would be an advantage to deliver and get a response from a continuous stream of WMT tasks that begin from the very first action of the play. The ability to use WMT in this way would force team tasks to be applied more procedurally, whilst freeing up activation in working memory for the players to adapt that team task to a new situation. Ultimately, this could allow the coach to use random and variable practice with WMT to develop deeply procedural and adaptable team tasks, where top-down resources are used only to manipulate information and adapt behavior, as opposed to using activation mostly for the storage of explicit/declarative knowledge. This would create a scenario where WMT is used to concurrently speed up and improve current actions whilst developing the potential to assimilate and apply actions in future exercises.

5.4.1.4 - Microsystem - Player adaptation to training methods helped the session progress easily for the coach and players

Video 5.15 2-back #1

Coding - Pre action, Unsuccessful FA, Verbal unsuccessful, Remote Unsuccessful

Researcher notes: Participants were unclear what the task was – needed to check understanding... another instance where a player forgot to use the remote.

Additional videos -

3-back #1

Coding - Pre action, Unsuccessful FA, Remote successful

Researcher notes - Successful N-back task, with participants demonstrating their understanding of the WMT tasks. (Referring to changes in difficulty)

Description and Analysis

Video 5.15 demonstrates what can occur in the training session if the exercise and tasks are not understood clearly before the action begins. The consequence is two-fold. First, valuable practice time is lost as the actions required by the team are not being practiced or developed if the players don't understand the exercise. Second, the use of WMT as an additional task can be undermined, as it appears to be an inconvenience, rather than an addition. This was able to be fixed quickly within the session as, due to previous training sessions, the players understood what the N-back task involved, as demonstrated by the comment "*was that a 2-back or a 3-back?".* Therefore, once the understanding of the exercise was clear, the players were able to perform the exercise with WMT. This demonstrates the importance of allowing for an adjustment period to WMT when prescribing it within a training program, bearing in mind that introducing too much WMT volume too soon could undermine the use of the method and socially invalidate its use within the team context. If the coach allows enough opportunity for the players to adjust to the methods, and ensures the exercise is fully understood, the use of WMT within an exercise can occur with minimal disruption.

5.4.1.5 - Microsystem - Individual labels allowed more accurate interpretation of results and recording of errors

Video 5.16 3-back#1

Coding - Pre action, Unsuccessful FA, Remote successful

Researcher notes: Successful N-back task, with participants demonstrating their understanding of the WMT tasks. (Referring to changes in difficulty)

Description and Analysis

Video 5.16 simply demonstrates the value of having individualised response profiles to WMT tasks, as any problems or issues in performing the WMT can be diagnosed and solved quickly. In this video the coach and researcher were able to check the answers of specific players, which by process of elimination, can help diagnose any issues in the remote system or task delivery. This was aided by the players understanding of WMT, asking questions to ensure they were performing the tasks correctly. The next step would be to deliver individualised WMT tasks to players, as well as receiving individual responses.

5.4.1.6 - Microsystem - Players had issues using the remote to respond to the task – wrong button, missed the button etc.

Video 5.17 Researcher Comments #9

Coding - Pre action, Unsuccessful FA, Verbal unsuccessful, Remote Unsuccessful

Researcher notes - Participants were unclear what the task was – needed to check understanding... another instance where a player forgot to use the remote.

Description and analysis

Video 5.17 captures a brief conversation that demonstrates the shortcomings of using a remote system for WMT. As found in Cycle 2, the use of a remote system introduces an additional non-specific motor task to performing a football action. In addition, players are also having to remember to both use the remote and choose which button to press in response to the task. Therefore, it is not only an additional motor task but an additional decision-making process on top of the WMT and football action. Whilst this would still be an example of working memory being overloaded, it is not a method of overloading that is intended. The impact of the task delivery and response method needs to be minimalised so that the difficulty of a task is dictated mostly by the football action required and the WMT task added. Verbal response may be a less complex (i.e. no extra consciously controlled motor task) method of responding, but then has the negative impact of having multiple results recorded at once. Based on this, methods of combining individual recording with a verbal response need to be investigated.

5.4.2 Reflection

This section reflects on the themes that emerged during Cycle 3, considering video data and researcher observations that are relevant to the themes identified, but not directly associated with specific video clips. As in the Cycle 2 reflection, no new themes will be identified, rather, data inserted in this section will only reinforce or help discuss those themes already identified. This section categorizes the themes that emerged and gives a brief explanation of the implications for the planning of future research, following into the next section where the analysis outcomes of this data collection are discussed.

Reflecting on Cycle 3, the following themes emerged through the triangulation of data, affecting the macro and micro systems of action:

1. Macrosystem - It was possible to use the N-back task during tasks that utilized a problem-solving pedagogy without interference on the structure of the exercise.
2. Macrosystem - Using WMT before players understood a task clearly meant that incorrect actions were performed and subsequently overloaded – which defeated the purpose, changed through dialogue between coach and researcher.
3. Macrosystem – Using the N-back as a start trigger meant that the entire sequence of play was completed with a WMT load.
4. Microsystem - Player adaptation to training methods helped the session progress easily for the coach and players.
5. Microsystem - Individual labels allowed more accurate interpretation of results and recording of errors.
6. Microsystem - Players had issues using the remote to respond to the task – wrong button, missed the button etc.

The above themes were organized into two categories, informing the planning of future action following this cycle. The categories were “Ways to improve coach-led WMT as part of the coaching process” (themes 1, 2, 3 and 4) and “Changes in CRS use that validate the need for improved technology” (themes 5 and 6).

5.4.2.1 Category 6: Ways to improve coach-led WMT as part of the coaching process

Contributing themes:

1. Macrosystem - It was possible to use the N-back task during tasks that utilized a problem-solving pedagogy without interference on the structure of the exercise
2. Macrosystem - Using WMT before players understood a task clearly meant that incorrect actions were performed and subsequently overloaded – which defeated the purpose, changed through dialogue between coach and researcher
3. Macrosystem - Using N-back as a start trigger meant that the entire sequence of play was completed with a WMT load
4. Microsystem - Player adaptation to training methods helped the session progress easily for the coach and players

Cycle 3 demonstrated how the use of WMT in a training session may vary based on the pedagogical approach being used, as well as some of the pitfalls of application that coaches need to account for. It is apparent in this cycle that WMT can be coach-led if used in pedagogies where feedback is not given in the moment, but in breaks between action. In addition, WMT can be used as a start trigger for exercises, and in the future, can be applied in a constant-stream format for the duration of play. Despite both findings, this cycle also demonstrated how the coach needs to ensure the participants clearly understand the exercises they are participating in, ensuring that they have achieved an adequate and repeatable solution to the exercise before overloading the actions with WMT. In addition, the adaptation of the participants to using WMT in training was beneficial when errors occurred in session delivery. The adaption of the participants is crucial to legitimise WMT as a viable training method within the session, as there is a danger that could be dismissed as irrelevant or “gimmicky”.

The ability to apply WMT in problem-solving pedagogy as a start trigger and constant stream allows the coach to not only make players responsible for finding solutions, but also creates the possibility to assimilate team and/or player tasks into procedural knowledge, whilst simultaneously preparing working memory to adapt that procedural knowledge to solve new problems. This could allow coaches to systematically use task-based learning and problem-solving with WMT and random practice as a cycle by which to develop a Playing Model that is weighted mostly as procedural knowledge. However, this would mean that the application of WMT volume would need to be adjusted to mastery basis, as opposed to a time basis. This has the advantage of creating an increased amount of available working memory capacity during the performance of the Playing Model, which can be used mostly for manipulation and adaptation. The newly available capacity would need to be mediated by directing attention appropriately. In practice, the outcome of such a process could be a team that is able to adapt a subconscious Playing Model to maximise the chances of winning matches in any context.

Finally, it is clear both in Cycle 3 and the previous cycles that the adaptation to using WMT is important in getting participants to accept it as a new training method. In addition, this cycle demonstrated that the coach also needs to check that the players understand the exercise, tasks, and possible solutions prior to introducing WMT.

In summary, the implications of Category 6 for future action are:

- Coaches need to ensure that players clearly understand the rules, constraints and solution(s) to a task before using WMT, which may mean WMT volume is prescribed with a mastery focus in these pedagogies.
- WMT can be used by the coach as both a start trigger and constant-stream task during pedagogies where immediate explicit feedback is not used.
- WMT could be used in combination with task-based learning, problem-solving and random practice as a method that develops the Playing Model of a team implicitly as procedural knowledge in the limbic system, whilst preparing the cognitive system to be used mostly for manipulation and adaptation of the Playing Model to new contexts.

5.4.2.2 Category 7: Changes in CRS use that validate the need for improved technology

Contributing themes:

5. Microsystem - Individual labels allowed more accurate interpretation of results and recording of errors.
6. Microsystem - Players had issues using the remote to respond to the task – wrong button, missed the button etc.

Cycle 3 demonstrated that the use of individualised WMT may be possible, and has clear benefits over non-individualisation, however, the method of response to the WMT tasks needs to be less invasive on the process of performing football actions. The use of individualised response profiles in the CRS system allowed the researcher to receive live responses to the tasks, whilst also allowing the researcher and coach to diagnose problems in the WMT delivery process – for example, whether the participants understood what task they were completing or whether they heard the task correctly. The next step in individualisation would be to send individualised WMT tasks, as players could require different difficulties of WMT whilst completing the same football actions. The ability to send and receive individualised tasks with an adaptive difficulty would mean that effective methods of lab-based WMT are being transferred to practice.

The challenge to delivering individualised and adaptive WMT to players during action is technology. The CRS provided a means to record individual responses, however, the use of a remote appears to require an additional non-specific motor task and decision making process. The impact of these additional processes on working memory is difficult to account for when compared to the prescription of WMT difficulty. Consequently, it would be beneficial to minimise the consciousness of any response process, which would ensure that the WMT task itself is the main mechanism of working memory overload. Implicit everyday processes such as speech may provide a solution, however, the technology to recognise speech would be required to record or distinguish a response. In addition, the use of speech may also impact the verbal communication of players. This problem needs further investigation to solve, as it is important to distinguish how much player actions are affected by the WMT tasks and/or the method of response for prescriptive purposes.

To conclude, the use of the CRS both advanced practice in Cycle 3, whilst also highlighting the limitations of available technology. The implications of Category 7 are:

- Technology that allows individualised and adaptive WMT to be sent and received with minimal conscious processing or impact on player actions needs to be researched.

5.4.3 Planning future action

Based on Cycle 3, the planning of future action should account for both the pedagogical integration of WMT and the method by which WMT is delivered. Specifically, future actions should consider that:

- Coaches need to ensure that players clearly understand the rules, constraints and solution(s) to a task before using WMT, which may mean WMT volume is prescribed with a mastery focus in these pedagogies.
- WMT can be used by the coach as both a start trigger and continuous task during pedagogies where immediate explicit feedback is not used.

If these factors are considered in the design of future training sessions, then future action would allow the investigation of:

- How WMT could be used systematically to develop the Playing Model of a team implicitly as procedural knowledge in the limbic system, whilst preparing the cognitive system to be used mostly for manipulation and adaptation of the Playing Model to new contexts.
- Technology that allows individualised and adaptive WMT to be sent and received with minimal conscious processing or impact on player actions needs to be researched.

Finally, whilst Category 6 provides guidance on the pedagogical integration of WMT that can be used immediately in future action, the need to improve the methods of delivery and response requires a design-based investigation that may be some distance from use in a training session. Therefore, “Category 8: Technology that could improve the delivery of WMT” has been added to guide future research outside of this study.

5.4.3.1 Category 8: Technology that could improve the delivery of WMT

Category 8 can be considered in two parts, first, what needs to be done to deliver WMT correctly, and second, what is required for integration into the training context. To deliver WMT correctly, technology needs to be able to achieve:

- Automated delivery of WMT tasks.
- Sending and receiving multiple individually adapted WMT tasks

For these objectives to be achieved, technology used may need to involve:

- Pre-recorded tasks.
- An alternative signal to infrared (such as wireless or cellular) that allows a greater signal distance.
- The use of wearable and ergonomically designed audio for the participants.
- A response method that limits the use of a secondary motor task or verbal response.

Prerecorded WMT tasks need to have consistent cadence, volume and need to be available across the range of WMT difficulties. Of the solutions above, this is the simplest, as the tasks only need to be recorded and stored. Achieving the prerecording and automation of tasks means that coaches or other staff are not required to deliver the tasks themselves, allowing them to focus on observation and feedback. This would address the negative impact of coach-led WMT across Cycles 1, 2 and 3.

The CRS system used in Cycles 2 and 3 used an infrared signal with a limited range, which created challenges in receiving task responses from participants. A readily available alternative would be a cellular or wireless internet signal, which can both allow large amounts of data to be sent and received in an outdoor setting, and with the use of a router, can support multiple devices. This would allow WMT to be used in larger exercises without having to carry around a sending/receiving unit, making this aspect of delivering WMT more reliable. The unit used to send and receive tasks would also need to be able to send and receive multiple tasks to and from multiple devices simultaneously, applying changes in WMT appropriately. In addition, the coaches/staff would need to be able to remotely stop and start the WMT as appropriate in the session.

To receive individual WMT tasks, each participant would need to be equipped with a receiver and audio that has a limited impact on performance. Bone conduction technology, which transmits sound by vibration through the cheek bones and doesn't block the ear canal, allows environmental sounds to remain detectable by the user (May and Walker, 2017), which may be helpful in limiting disruption on verbal communication during play. However, May and Walker (2017) did also find that use of Bone Conduction could also be associated with a decline in environmental awareness, which could be associated with the capacity and/or efficiency of the phonological loop. In comparison, headphone technology which blocks the ear canal may prevent a participant from detecting environmental sounds at all, so whilst the impact of bone conduction on awareness could have a degree of impact on completing WMT and football actions, the technology would at least still allow a participant to retain a significant degree of the ability to detect, store and manipulate aural information. Furthermore, any technology used would need to be ergonomically suitable for use in football, standing up to factors such as movement and sweat, whilst posing minimal risk of injury in contact situations. This means a traditional headband-type design may not be suitable, as these could pose a similar risk to jewelry such as wristbands or necklaces, which aren’t permitted to be worn in competition for safety reasons.

Providing the response method that has the least interference on performing domain-specific actions presents challenges. This research used both a verbal and remote method, which each presented its own limitations. The verbal response method seems to pose fewer problems in response, but significantly affects the delivery of the coach and limits both the number of participants that can receive a task at once and the ability to individualise the WMT tasks, whilst also affecting verbal communication. The remote method allows multiple individuals to respond at once, and allows players to verbally communicate with each other as normal - but introduces an additional motor task and conscious process (selecting the right button) which impacts the ability to distinguish the effect of WMT on an action from the impact of response method on an action. It seems that verbal response is a method by which to limit the introduction of additional motor tasks and conscious processes (as speech would be largely implicit). It also seems that a remote system is a method of limiting the impact on verbal communication.

A potential solution could be the use of sub-vocalisation technology, such as the AlterEgo system (Kapur, Kapur and Maes, 2018), which provides the user with a silent speech interface that can be used to communicate with computers or other users. The system uses bone conduction to receive audio and detects the neuromuscular signals that occur in response to the intention to speak or the internal speech of the user to send audio. The device does not respond to verbalised speech. The impact and ergonomic suitability of such a device in sport and/or football is unknown, however, it could provide a solution that combines the benefits of verbal and remote response methods – limiting the impact on player actions and verbal communication whilst allowing automated WMT task delivery, and response, to and from multiple users. The benefit would be that the impact of WMT on actions, not the method of response, could be easier to perceive and quantify.

In summary, Category 8 provides guidance on the next step in researching how WMT can be integrated into Football Coaching. Aspects of future research can be listed as:

- The use of pre-recorded and automated tasks with consistent cadence.
- A WMT send/receive system that uses a cellular/wireless signal to communicate with multiple devices and adjusts the difficulty for each individual based on the WMT difficulty algorithm.
- The ability for coaches to stop and start WMT remotely.
- Using ergonomically appropriate Bone Conduction technology to allow players to receive tasks whilst limiting the impact on receiving aural information (May and Walker, 2017).
- Testing the ability of sub-vocalisation technology such as the AlterEgo system (Kapur et al., 2018) to allow participants to receive WMT tasks and give a non-verbal response whilst completing football actions.

The outcome of future research would be to develop a system that incorporates the above points into a solution that allows WMT to be used in coaching practice with minimal interference. This would leave further adaptations of practice to be largely pedagogical and provide a genuine training tool by which coaches can systemise and periodise both the assimilation of an implicit Playing Model, but also the ability to adapt that model to increasingly complex situations. The development of that system may also help in accurately quantifying the impact of WMT on expertise in sport. These implications will be discussed in a wider context during the thesis discussion in Chapter 8. The following section summarises the data analysis and implications of this study.

5.6 Data analysis outcomes

The PAR approach to this study allowed a number of categories to emerge across the three cycles of planning, action and reflection that took place. Table 5.1 lists all the categories that emerged, organised by cycle, to give an overview of the findings from this study.

Table 5.1 Categories that emerged from the data analysis

Cycle	Category	Description/Outcomes
Cycle 1	Category 1: Aural task delivery	There needs to be an investigation into wearable audio for participants to ensure task volume is correct.
		Pre-recording tasks OR consistency in coach delivery will control cadence correctly.
		A constant stream WMT task, such as the N-back may make it possible to deliver WMT tasks to an entire team during play.
		A non-verbal, simultaneous response method for participants needs to be investigated to receive results from an entire team during play.
	Category 2: WMT task effects	The impact of lab-based WMT seems to be somewhat replicated by WMT use in the football context.
		Refined application methods will allow more accurate validation of the merits of using WMT in the football context.
	Category 3: WMT difficulty prescription	Adaptive training difficulty needs to be applied where possible, therefore the success rate of participants needs to be recorded during training, with external factors that directly influence success being considered.
		It is necessary to investigate how individually adapted tasks could be sent to each participant within a group setting, with individual responses also recorded to adapt the WMT difficulty level for each participant.
Cycle 2	Category 4: The negative impact of coach-led WMT on the coaching process	Automated delivery of WMT is preferable to coach-led delivery
		WMT prescription needs to account for the game resistances (opposition, playing area, rules etc.) of an exercise relative to the level of the individual, which also means the coach must have an awareness of how exercises and actions will be progressed logically throughout a competitive season.
		A pre-training induction to WMT is required to speed up the adaptation of participants in using WMT. The length and detail of induction and subsequent adaptation will depend on the future delivery methods of WMT, discussed in the following category.
	Category 5: Developing task delivery and response	A response method that does not require a secondary motor task needs to be investigated.
		An alternative signal to infrared (such as wireless or cellular) needs to be used to transmit responses over a greater distance.
		Individual response profiles need to be set up for the CRS.
		The use of wearable audio for the participants needs to be incorporated.

Cycle 3	Category 6: Ways to improve coach-led WMT as part of the coaching process	Coaches need to ensure that players clearly understand the rules, constraints and solution(s) to a task before using WMT, which may mean WMT volume is prescribed with a mastery focus in these pedagogies. WMT can be used by the coach as both a start trigger and constant stream task during pedagogies where immediate explicit feedback is not used. WMT could be used in combination with task-based learning, problem-solving and random practice as a method that develops the Playing Model of a team implicitly as procedural knowledge in the limbic system, whilst preparing the cognitive system to be used mostly for manipulation and adaptation of the Playing Model to new contexts.
	Category 7: Changes in CRS use that validate the need for improved technology	Technology that allows individualised and adaptive WMT to be sent and received with minimal conscious processing or impact or impact on player actions needs to be researched.
	Category 8: Technology that could improve the delivery of WMT	The use of prerecorded and automated tasks with consistent cadence. A WMT send/receive system that uses a cellular/wireless signal to communicate with multiple devices and adjusts the difficulty for each individual based on the WMT difficulty algorithm. The ability for coaches to stop and start WMT remotely. Using ergonomically appropriate Bone Conduction technology to allow players to receive tasks whilst limiting the impact on receiving aural information (May and Walker, 2017). Testing the ability of sub-vocalisation technology such as the AlterEgo system (Kapur et al., 2018) to allow participants to receive WMT tasks and give a non-verbal response whilst completing football actions.

5.7 Conclusion – Applying WMT in Football Coaching using PAR

This Chapter detailed a PAR investigation on the application of WMT within a Football Coaching context, through the lens of Systemic Creativity, Flow theory and perceptual-cognitive skill. Three cycles of PAR were performed, with video, semi-structured interview, coach-researcher interaction and researcher observation coded and triangulated for analysis. The analysis of each cycle was presented thematically using a video example and analytical description of each theme. The reflection of each cycle combined the themes that emerged into a category that would shape the planning of the next cycle. Eight categories were identified throughout the research process and are tabulated with a description/outcome listed in Table 5.3. This use of PAR both solved and highlighted, through collaboration with participants, pedagogical and technical factors that need be investigated for WMT to be used successfully within Football Coaching in the future. In conclusion, this Chapter has created a foundation from which further research can continue the process of investigating how WMT can be used in Football Coaching, and eventually, quantifying the performance impact of such an approach. The technological needs of future research may present significant costs in both time and funding. Research that attempts to quantify the impact of WMT on skill performance still needs to be performed in order to help validate or dismiss the need for further development of technology and pedagogy. Following this objective, Chapters 6 and 7 detail studies 2 and 3, investigating the impact of WMT on the performance of a football skill using quantitative measures.

Moving from qualitative to quantitative investigation: Introducing Chapters 6 and 7 (Studies 2 and 3)

The first part of this research (Chapter 2) asked what form of training would be suitable for developing the structures supporting Perception, Decision Making and Execution in football. Then the second part of this research (Chapters 3-5) asked how WMT could be systemised and conducted in the context of football coaching, which simultaneously transitioned the sequence of research from theorising into investigation. Chapter 5 (Study 1) culminated in the categorisation of how the practical use of WMT in football coaching could be developed, laying a foundation for future applied work.

Now that the practical application of WMT is better understood, it is important to investigate whether the use of WMT can impact performance in a positive manner, as both practicality and performance benefit need to be understood for there to be real implications on practice. The sequence of research therefore moves into part three, which focuses on investigation. The following two Chapters (6 and 7) seek to investigate how WMT impacts skill performance in football through two studies (studies 2 and 3). These studies were both performed with publication in mind and are structured as journal articles with a brief introduction based on Chapter 2 of this research. Study 2 is detailed in Chapter 6, investigating the impact of a minimum dose of WMT on performance on the LSPT, whilst Study 3 is detailed in Chapter 7, investigating the impact of a minimum dose of WMT on performance in an LSPT-Stroop test. The work detailed in the following chapters is designed to complement the qualitative work in Chapter 5 with quantitative work on the influence of WMT. The combination of qualitative and quantitative work is intended to provide a well-rounded context for WMT, creating a foundation for discussion in Chapter 8 and any practical implications stemming from this research.

Chapter 6

Study 2: Does a minimum dose of WMT during football skill performance impact results on a football skill test?

6.1 Introduction

Working Memory is a construct described by Baddeley (2003) as responsible for temporary storage and manipulation of information, allowing planning of future action. Working memory has a limited capacity (Just and Carpenter, 1992) varying between individuals, with evidence that the efficient use of working memory capacity is trainable (Constantinidis and Klingberg, 2016). Research on perceptual-cognitive expertise in sport has found that experts can be differentiated from non-experts by the effective use of working memory capacity during action (Vestberg et al., 2012). This differentiation is linked to differences between experts and non-experts in perceptual-cognitive characteristics such as motor inhibition (Verburgh et al., 2014), visual search (Mann et al. 2007) and cue recognition (Ward and Williams, 2003) – all requiring the mediation of bottom-up limbic signals by top-down cognitive signals (which can also be referred to as subconscious and conscious respectively). If working memory capacity is limited during an action, the system can be overloaded by limbic and/or cognitive signals (including emotional responses such as anxiety) causing a break down in performance known as “Choking” (Bijleveld and Veling, 2014). Therefore, it is desirable for athletes to have greater available working memory capacity during action, limiting the probability of Choking due to working memory overload whilst facilitating perceptual-cognitive processes such as motor inhibition, visual search and cue recognition. This is related to the development and use of more efficient cognitive or limbic signals, which can be achieved through specific methods of learning and training.

Perceptual-cognitive skill has been developed in sport using pedagogical methods that incorporate implicit learning strategies such as dual tasking, constraint-based exercises (Gabbett and Masters, 2011) or analogy learning (Liao and Masters, 2001). These strategies can be used to develop perceptual-cognitive skill throughout the life span, although with a slower rate relative to age, noted in 12-19-year-old adults by Vestberg et al. (2012) and Verburgh et al. (2014), whilst in WMT research it has been found that adults improved functions such as processing speed and inhibition after a WMT intervention (Smith et al., 2009; Brehmer et al., 2011; Bastian et al., 2013). However, whilst perceptual-cognitive training methods encourage the acquisition of implicit motor skills and decision-making processes, there is little evidence of specific and systematic development of the underlying structures, such as working memory, that support the improvement of perceptual-cognitive skill. This is because strategies such as dual tasking limit the use of working memory during action (Maxwell et al., 2003) by simply occupying activation, in contrast to systematic WMT.

Previous research on dual tasking methods and perceptual-cognitive training have used either domain-general lab-based methods (Faubert and Sidebottom, 2012) or on field exercises that were found to be impractical (Gabbett and Masters, 2011). Each paper presents two problems respectively, first, that lab-based methods could not be transferred into effective on-field methods as part of coaching pedagogy, and secondly, that the attempted on-field methods only occupied working memory as an interference instead of training working memory. Therefore, existing methods do not address the idea that we could develop domain-specific working memory through systematic training interventions that target working memory during the performance of actions.

WMT can be differentiated from previously used dual tasking methods first by evidence of improving working memory function in the literature (Jaeggi et al., 2008, Smith et al., 2009; Takeuchi et al., 2011; Loosli et al., 2011, Brehmer et al., 2011; Schneiders et al., 2012; Brehmer et al., 2012; Bastian et al., 2013; von Bastian and Oberauer, 2013). Secondly, the presence of systematic training principles relating to training volume and frequency and thirdly, the adaptation of difficulty to individual ability (von Bastian and Oberauer, 2012; Bastian et al. 2013). These characteristics of WMT allow it to be applied as a training program that can be individualised, with previous evidence showing that WMT tasks such as the Digit Span (Brehmer et al., 2012) and N-back (Altgassen et al., 2007) have been effective in improving working memory function, albeit in a lab-based setting. Whilst it has been found that novel working memory tasks can be used to elicit improvement in participants (Smith et al., 2009; Loosli et al., 2011), many studies, as noted in section 2.2, that found evidence of improvement in working memory function have used N-back tasks (Heinzel et al., 2013; Schneiders et al., 2012). The N-back task requires participants to temporarily store and manipulate items in an item matching task.

The aim of this study was to investigate the effects of WMT on football skill development. Study 1 used an action research methodology which investigated how WMT can be applied in Football Coaching pedagogy, this study is designed as an initial test of how the use of WMT in Football Coaching can impact on football skill performance. Assuming that the LSPT replicates the demands of skill performance in football, this study hypothesises that the use of WMT should illicit an improvement in skill performance following a minimum training dose.

6.2 Methods

This study used an experimental approach comprising a pre-post-test and time-series design, anticipated to not only investigate the post-intervention effects of WMT but to also investigate fluctuations in performance during the WMT intervention. The intervention took place over a four-week period with an Experimental Group, Active Control group and Passive Control group. The Experimental and Active Control participants trained twice per week for a minimum fifteen-minute training dose. The pre and post test results were analysed using pair-samples T-Test, effect size and time series.

6.2.1 Participants

Participants in this study were 24 sub-elite (competing in the top tier of a regional competition) male football players (age M=20±2.5 years) divided equally and randomly into Experimental (n=8), Active Control (n=8) and Passive Control groups (n=8). The Active Control group completed the football skill tests and intervention without a WMT intervention, whilst the Experimental Group completed the football skills tests and intervention with a WMT intervention. The Passive Control group completed only a pre-test and post-test. The participants completed testing and the intervention over the course of their football training week, which involved two training sessions, two days apart, over a period of four weeks, resulting in a total of seven training sessions in between the pre- and post-tests. The four-week period was selected as it provided both a minimum dose of WMT and a practical time period for the participants to complete the intervention in full. 8 participants had their data removed from the study due to missing data during the intervention or the post test, leaving a sample size of 16 participants between the Experimental (n=7), Active Control (n=5) and Passive Control Groups (n=4). The participants agreed voluntarily to complete the study, which was approved by the Human Ethics Committee at the University of Canterbury.

6.2.2 Test and intervention instruments

The LSPT

The LSPT (Ali, Williams and Hulse et al., 2007; Ali, Foskett and Gant, 2008; Ali, 2011) is a test for measuring passing skill in football. The LSPT was developed as a test that combines the physiological, decision making and skill execution elements of performance in football (Ali et al. 2007) whilst avoiding the potential subjectivity in assessing skill during match play, or the non-specific testing of isolated techniques without decision making or physiological demands (Ali, 2011).

The LSPT required participants to complete sixteen passes over varying distances (eight short passes and eight long passes) to four different coloured targets placed on four benches within a time frame of 43s. The targets were pre-set by the instructor using randomly generated trial orders. The Overall Time (Penalty Time plus Completion Time) taken to complete the task was taken as a measure of how well the athlete could perform the task. Penalty Time was added for mistakes such as passing to the wrong target or missing the bench (5s), missing the target (3s), handling the ball (3s), hitting a cone with the ball (2s), passing the ball outside of the designated area (2s) or completing the task too slowly (1s for every second taken over the allocated 43s to complete the test). Time could be won back by passing accurately to the 10cm strip in the middle of each target (1s). Each target was called out by the instructor just before the participant completed the current pass and once the participant received the ball, they had to cross two of the internal lines (white cones – see Image 1.1) before making the next pass.

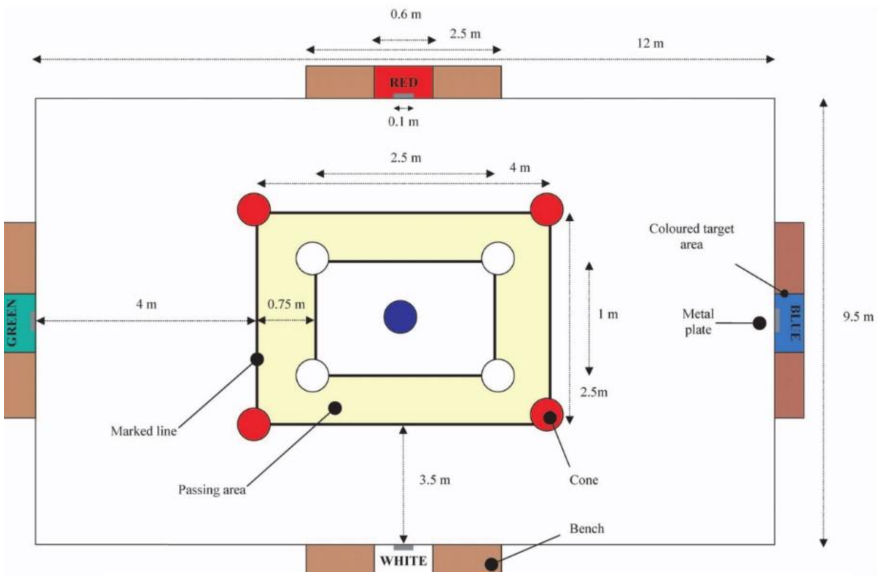


Figure 6.1 The LSPT (Ali et al., 2008)

Validity and reliability of the LSPT were investigated in elite and sub-elite male football players by Ali et al. (2007) and in elite and sub-elite female football players in Ali et al. (2008). Both validity and reliability studies (following familiarisation) used two trials conducted a week apart, finding that elite players performed better than non-elite players on the LSPT with a smaller difference in total time between the two trials also shown in elite players. Ali et al. (2007) reported the RLOA (Ratio Limits of Agreement) for total time on the LSPT as 0.92 (Intra-class correlation coefficient=0.64), whilst Ali et al. (2008) reported 0.96 (correlation=0.73). Both studies demonstrate that the test can reliably differentiate between male or female elite and sub-elite football players.

WMT within the LSPT

The LSPT was used both as a testing instrument and a training intervention for this study.

The Experimental and Active Control groups performed the LSPT for two sessions of fifteen minutes per week as part of their team training sessions, with WMT added to the LSPT for the Experimental Group. Within each 15-minute session, the participants completed five LSPT trials with the best scores for Penalty Time, Completion Time and Overall Time recorded. The participants had 3 minutes of recovery between trials. The WMT task used for the intervention was the N-back task, incorporated as a novel task that used the coloured targets of the LSPT as the items of the N-back. The N-back task was combined with the coloured targets and forced the participants to pass to the target that was N places back in the order of colours called out by the instructor, this meant that the instructor would call out N colours prior to the participant making the first pass. This meant that on a 2-back, the instructor would call out 2 trials prior to the participant making their first pass. As the participants were completing 16 passes, the instructor called out 18 trials for a 2-back, 19 for a 3-back and so forth. The instructor called out the trials when the ball was travelling towards the target, giving the participants an opportunity to perceive where they would attempt their next pass.

The difficulty of the WMT tasks was adjusted based on the performance of the participants on the scoring of the LSPT. The adjustment of WMT task difficulty was based on the algorithm suggested by von Bastian and Oberauer (2013), whilst changes in the LSPT score of participants were monitored to ensure that challenge and success were adequately balanced. If the participant was within a twenty percent scoring range of their mean LSPT score from the previous session, then the difficulty of the WMT was raised. If the participants scored between fifty and eighty percent of the scoring range of their mean LSPT score from the previous session, then the difficulty of the WMT remained the same.

If the participants were underneath a fifty percent scoring range of their mean LSPT score from the previous session the difficulty of the WMT was lowered. For the N-back/LSPT task, the difficulty was based on the magnitude of N, ranging from 1-back to 4-back. The training dose was consistent with the use of distributed WMT being shown as more effective than concentrated training (Penner et al., 2012). The volume of WMT was set at fifteen minutes per training based on studies examined in section 2.2 that showed trained and transfer effects of WMT, ranging from fifteen minutes to forty-five minutes (for example, Chein and Morrison, 2010)

6.2.3 Procedure

The pre- and post-tests took place two days before the first training session and two days after the final training session respectively. The pre- and post-tests required each participant to complete three attempts at the LSPT after a practice attempt beforehand. The participants were instructed to complete the test as quickly and accurately as possible, aiming for the best Overall Time. The individual scores for these tests were collected and the best score for Penalty Time, Completion Time and Overall Time was taken for comparison. This allowed the study to assess the impact of the intervention on performance, comparing the use of WMT to not using WMT, whilst also accounting for the impact of a learning effect during the pre-test and changes in speed or accuracy between tests. The time series data, comprising of Penalty Time, Completion Time and Overall Time, was collected as part of each training session to monitor and score both the WMT and the LSPT and deliver the correct WMT dose for each participant. The time series data allowed the observation of how performance was impacted throughout the intervention whilst recording speed and accuracy separately allowed the study to understand how these two measures fluctuated throughout the intervention.

6.2.3 Statistical analysis

Data analysis was performed by first looking for significant differences between pre- and post-test results, then by comparing effects between groups. The analysis sought to understand any significance or effects sizes by analysing time-series data to gain insight into how impacts of the intervention may have occurred. The pre-test and post-test data were analysed using a paired-samples t-test to measure significant differences within groups. To account for the limited sample size, post hoc analysis used Cohen's *d*, Glass' Δ and Hedges' *g* to describe effect sizes between the Experimental group and Active/Passive Control groups whilst accounting for potential biases caused by SD differences and/or differences in sample size. Due to the differences in sample size and SD between the groups, a Mean Effect Size was also calculated in the analysis. The magnitude of effect sizes was noted based on the levels found in Sullivan and Feinn (2012). Time-series data was graphed to map how performance was affected between the pre-test and post-test. Changes in WMT difficulty for the Experimental group were collected with the Mean Max Difficulty, Mean Session Difficulty and Mean Session/Trial Difficulty Progression calculated. Collecting WMT difficulty changes helped to confirm whether WMT was being administered with a degree of accuracy during the intervention.

6.3 Results

Pre/Post-test Data

Pre and post-test data were analysed first for significance in paired t-test results within groups, then for effect size between groups.

Table 6.1 Mean ± for Pre/Post LSPT Results

	Completion Time (s)				Penalty Time (s)				Overall Time (s)			
	Pre-Test		Post-Test		Pre-Test		Post-Test		Pre-Test		Post-Test	
Active Control (n = 5)	43.20	± 2.6	43.26	± 2.1	4.40	± 5.7	-0.80	± 6.4	49.86	± 6.87	42.48	± 6.2
Passive Control (n = 4)	41.03	± 1.4	42.23	± 0.9	10.50	± 6.0	16.00	± 7.2	52.78	± 8.84	59.38	± 7.3
Experimental (n = 7)	43.56	± 3.7	42.69	± 1.7	6.43	± 9.2	-0.86	± 4.6	51.27	± 8.90	42.86	± 4.8

Table 6.2 Mean differences in Penalty, Completion and Overall Time within groups

	Comp. Time Difference			Pen. Time Difference			Overall Time Difference		
	Mean	SD	p	Mean	SD	p	Mean	SD	p
Active Control (n = 5)	0.06	±1.48	0.93	5.20	±9.18	0.27	7.38	±11.4 6	0.22
Passive Control (n = 4)	1.20	±1.43	0.19	5.50	±4.80	0.11	6.60	±5.68	0.10
Experimental (n = 7)	0.87	±3.60	0.55	7.29	±9.50	0.09	8.41	±7.94	0.03*

*Significant difference (p = < 0.05)

There was a significant difference for the Experimental Group between the pre-test Overall Time (M=51.27, SD=8.9) and the post-test Overall Time (M=42.86, SD=7.94), $t_{(6)}$=2.805, p = 0.03). This result indicates an improvement in overall performance (combined speed and accuracy) for the Experimental Group. However, the sample sizes of the study limit the calculation of statistical significance. Therefore, the effect sizes have been considered in the analysis, as presented below:

Table 6.3 Effect sizes of pre/post Mean Differences between Experimental Group and Active/Passive Control

			Mean Diff	SDAv	*d*	Δ	*g*	*M* Effect Size
Completion Time	Experimental Group (n = 7)	AC (n = 5)	0.93	2.54	0.37*	0.63**	0.32*	0.44*
		PC (n = 4)	2.07	2.51	0.82***	1.45***	0.68**	0.98***
Penalty Time	Experimental Group (n = 7)	AC (n = 5)	2.09	9.34	0.22*	0.23*	0.22*	0.22*
		PC (n = 4)	1.79	2.51	0.71**	0.37*	0.22*	0.43*
Overall Time	Experimental Group (n = 7)	AC (n = 5)	1.03	9.70	0.11	0.09	0.11	0.10
		PC (n = 4)	1.81	6.81	0.27*	0.32*	0.25*	0.28*

*small effect 0.2, **medium effect 0.5, *** large effect 0.8, (Sullivan and Feinn, 2012)

Effect sizes of the mean differences between groups showed a small effect between the Experimental Group and Active Control for Completion Time (*d*=0.37, Δ=0.63, *g*=0.32, *M* Effect=0.44) and Penalty Time (*d*=0.22, Δ=*0.23*, *g =0.22*, *M* Effect=0.22). Between the

Experimental Group and Passive Control there was a small effect for Penalty Time (d=0.71, Δ=0.37, g=0.22, M Effect=0.43) and Overall Time (d=0.27, Δ=0.32, g= 0.25, M Effect=0.1), whereas there was as large effect on Completion Time (d=0.82, Δ=1.45, g=0.68, M Effect=0.98). These results suggest a difference between the Experimental Group and Passive Control, indicating that training had more impact on test performance than non-training. However, the effects between the Experimental Group and Active Control Group suggest that the use of WMT made little difference in performance between the groups. Given the novelty of this study, this may indicate a methodological issue in the prescription of WMT and/or that WMT was an ineffective training tool in the context of this study.

Time Series Data

Throughout the intervention, the best scores in Completion Time, Penalty Time and Overall Time were taken from each session (including the pre-test and post-test) to assess changes in performance in the Experimental Group and Active Control Group. The following figures present the changes in each measure throughout the study.

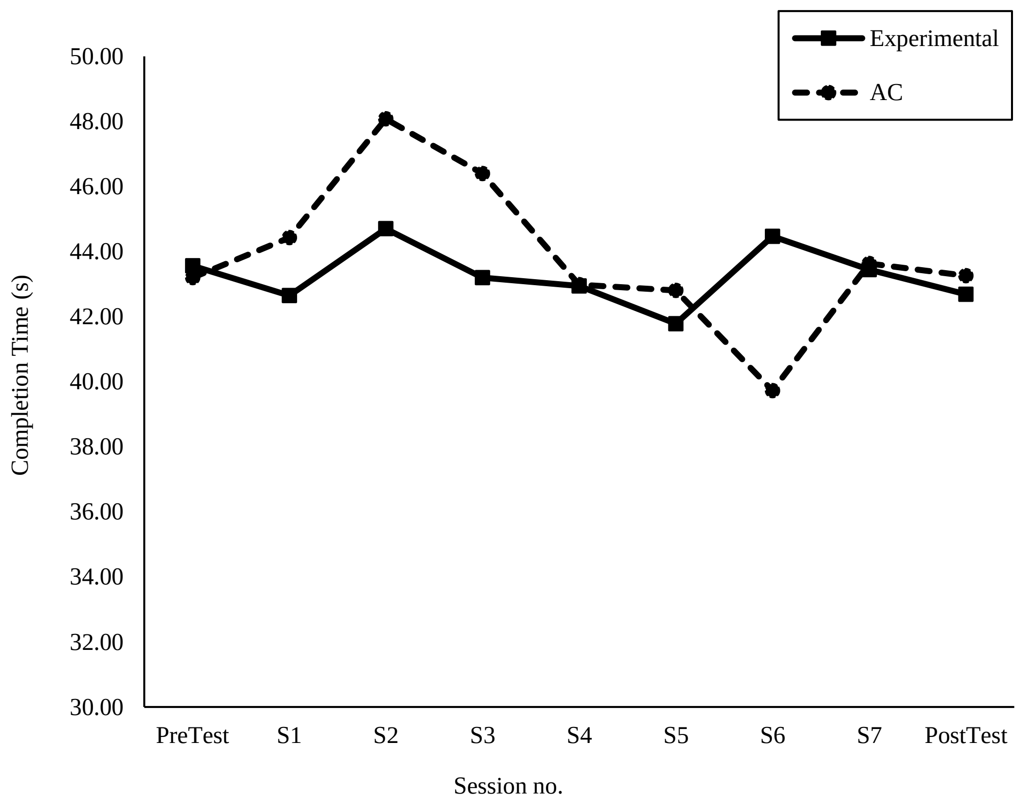


Figure 6.1 Time-Series: Sequential Changes in Mean Completion Time Between Experimental and Active Control Groups

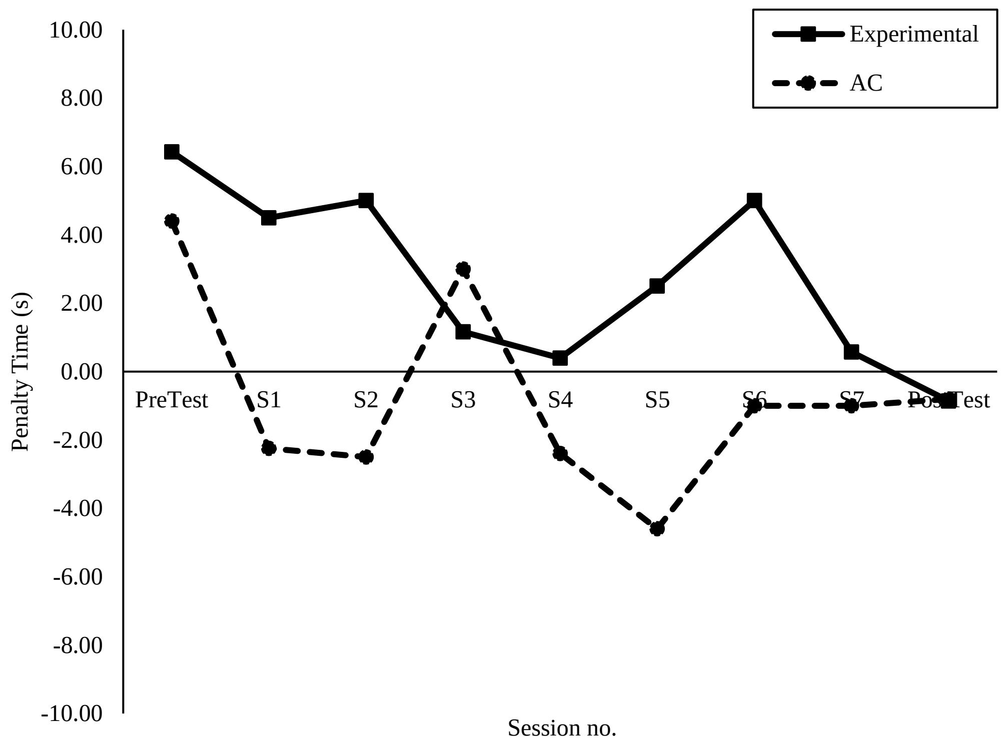


Figure 6.2 Time-Series: Sequential Changes in Mean Penalty Time Between Experimental and Active Control Groups

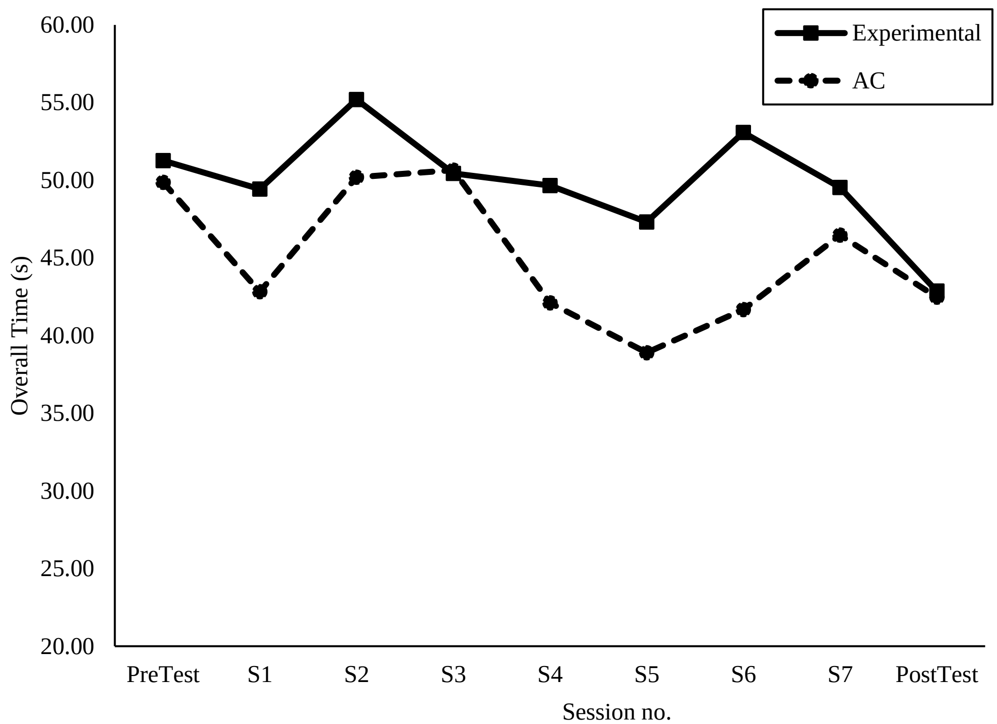


Figure 6.3 Time-Series: Sequential Changes in Mean Overall Time Between Experimental and Active Control Groups

The time-series data demonstrates that both the Experimental Group and Active Control Group improved results in accuracy but not speed, with a knock-on effect to an improvement in Overall Time. The data shows that the Experimental Group improved accuracy to a greater degree than the Active Control, albeit with limited significance and effect size (presented earlier). The Active Control group went through extreme changes in performance throughout the intervention, which appear to show the upper and lower limits of an overall trend in each measure. The data may also indicate a dual-task effect in the Experimental Group following the pre-test, increasing speed relative to the Active Control. Otherwise, the time-series data appears to show a micro progressive-overload curve for both groups, albeit with slightly different timing in recovery and supercompensation.

WMT difficulty progression data

Changes in WMT difficulty during the study were recorded to aid understanding of whether the WMT tasks prescribed affected working memory performance. These changes are shown in Tables 6.4 and 6.5:

Table 6.4 Mean ± N-back Difficulty by session no.

(n = 7)	N-back Session 1	N-back Session 2	N-back Session 3	N-back Session 4	N-back Session 5	N-back Session 6	N-back Session 7
M	2.5 ±0.6	3.0 ±0.8	2.6 ±0.5	2.5 ±0.6	2.7 ±0.5	2.8 ±0.4	2.9 ±0.4

Table 6.5 displays descriptive statistics of the changes in N-back difficulty for the Experimental Group. The “N-back Max” value reflects the highest level a participant completed, which in some cases was followed by the participants dropping down a level in difficulty, creating a slight difference between the N-back Session 7 result in Table 4 (M=2.9, SD=0.4) and the N-back Max value displayed in table 5 (M=3, SD=0.58). The “N-back Start” value indicates the N-back level the participants had progressed to by the end of their first training session.

Table 6.5 Analysis of changes in N-back difficulty

(n = 7)	Sessions	Trials	N-back Start	N-back Max	N-back Mean	N-back Progression /Session	N-back Progression /Trial	N-back Difference
M	5.43 ±0.79	27.14 ±3.93	2.29 ±0.49	3.00 ±0.58	2.70±0.40	0.24 ±0.20	0.05 ±0.04	1.29 ±0.95

The results indicate that the Experimental Group (n=7) progressed from a similar difficulty of M=2.29 (SD=0.49) by the end of their first training session, to a maximum of M=3.00 (SD=0.58) during the intervention, with a mean difficulty of M=2.7 (SD=0.4) throughout the intervention. These results suggest the WMT dose used in this study had little impact on working memory performance, whilst the immediate progression to a difficulty of M=2.29 (SD=0.49) suggests a methodological issue questioning whether working memory was required for performance in the LSPT.

6.4 Discussion

The aim of this study was to investigate the use of WMT in combination with a football skill training protocol and test whether any significant performance changes on skill performance were present. It was hypothesised that the WMT would have a positive impact on performance. The results of this study show that there was a significant difference (p=0.03) in Overall Time for the Experimental Group between pre-test and post-test measures, which may have been related to improvements in accuracy. The effect size data showed small effect between the Experimental Group (n=10) and Active Control (n=10) for Completion Time (d=0.44, Δ=0.32) and Overall Time (d=0.39, Δ=0.35), as well as a large effect in Penalty Time (d=0.87, Δ=0.78). Between the Experimental Group and the Passive Control, small effect was found for Overall Time (d=0.21, g=0.2), medium effect was found for Completion Time (d=0.65, g=0.65) and large effect was found for Penalty Time (*d*=0.97, *g*=0.84). Time series data reflected little difference in Completion Time (speed) but did indicate that WMT may have had an impact on Penalty Time (accuracy) during the intervention. The N-back data shows that the Experimental Group (n=7) progressed from a difficulty of M=2.29 (SD=0.49) by the end of their first training session, to a maximum of M=3.00 (SD=0.58) during the intervention, with a mean difficulty of M=2.7 (SD=0.4) throughout the intervention. These results and their implications are discussed below

The first finding of this research is that the use of WMT appeared to impact accuracy to a greater degree than speed, with a knock-on effect on Overall Time, as shown in the t-test, effect size and time-series data. This is somewhat consistent with the findings of Smith et al. (2017), who investigated performance on the LSPT under mental fatigue. Following a thirty-minute dose of the Stroop task Smith et al. (2017) found that mental fatigue impacted passing accuracy, not speed, on the LSPT and suggested that this may be due to a speed-accuracy trade-off under limited attention, linking the finding to previous research on a tapping task by Rozand et al. (2015). This finding suggests that the removal of and/or decrease in difficulty of WMT may have had a positive impact on accuracy. Further studies with a larger sample would be required to validate any such claim.

The second finding of this research relates to issues in the prescription of WMT. Managing and prescribing the correct difficulty of WMT was complex due to the nature of the WMT tasks used and the amount of time required for each action performed on the LSPT. This study prescribed the difficulty of WMT tasks in response to the Overall Time recorded by the participants. The LSPT requires 16 passes to be performed within a target time of 43 seconds, therefore requiring an action every 2.68 seconds, whilst working memory has a limited duration for which items can be held and manipulated (Constantinidis and Klingberg, 2016). Theoretically, if a 3-back was performed, the participant was attempting to match new items with an item that was stored approximately 8.04s previously, whilst a 4-back would have required recall and matching of items over a duration of 10.72s. These times may exceed the duration for which working memory can hold the initial item (relative to the individual), making the task unachievable, rather than difficult, which may mean that a 4-back is the highest achievable level of N-back in the LSPT… if participants complete the test close to the target time. In addition, this limitation to the difficulty of WMT means that each difficulty change represented a significant increase or decrease in difficulty. This was reflected during the training of the WMT group when participants moved between difficulties regularly with major observable differences in accuracy. This research therefore suggests that a more sensitive difficulty algorithm needs to be developed and applied to limit erratic changes in difficulty, with a greater focus on skill accuracy during the LSPT, utilising action-based measurements. In summary, slower and more accurate changes in WMT difficulty, in response to the accuracy of actions, should be used during future research.

One question this research highlights is the validity of using the LSPT in its current form to assess skill performance in football. The LSPT has been questioned recently as an accurate representation of football skill performance, on the basis that it has poor validity when compared to objective match analysis (Serpiello et al. 2017). This research suggests the issue may lie in the "decision making" element of the LSPT (Ali, 2011), which appears to lack the demand for controlled and/or selective attention (two functions linked with a requirement for working memory use - Furley and Wood, 2016) that performance in a match situation would require. Furley and Wood (2016) suggest that the contextual factors of sport determine how working memory is used, based on the idea that skilled performance requires athletes to deal with, first, concurrent distraction and second, interference from prior experience or habit (adapting learned skills to a situation – for example, time and space determined by the opponent).

A potential problem with the LSPT used in the study is that whilst it achieved concurrent distraction through dual tasking WMT, the test lacks the variation required to create interference from prior experience, as the passing distance, dribbling space and pass zones all remain constant. This means that there is a lack of selective/controlled attention to discriminate between stimuli and pair appropriate motor tasks, and therefore a lack of manipulation and use of the episodic buffer in working memory during the LSPT. This could be a contributing factor to the lack of significant effects within the experimental group in the pre-and post-tests, along with the N-back levels achieved by the end of the first training session, with only a small improvement recorded up to the seventh session. Theoretically, if the LSPT did require significant working memory load, then participants wouldn't have been able to achieve such a high WMT difficulty level by the end of the first session, and the impact of WMT dose on the pre and post-test results would have been greater. The magnitude of working memory use in the LSPT may also be reflected in the small effect sizes recorded between the Experimental Group and Active Control Group.

Finally, it is noted that the Passive Control recorded a decrease in performance between the pre-test and post-test. The tests took place four weeks apart, so the decrease in performance may reflect a change in performance related to factors external to this study, or that the participants became unfamiliar with the LSPT. The researchers attempted to mitigate the possibility of participants becoming unfamiliar with the LSPT protocol by explaining and demonstrating the test in the same manner prior to both tests, so either this was ineffective, or external factors played a role.

In summary, adapting the LSPT to include controlled and/or selective attentional functions could increase the likelihood of accurately measuring the impact of WMT, as working memory and its associated functions are established as underpinning perceptual-cognitive skill. Developing the LSPT to incorporate greater working memory use and closer reflect practice will help bridge the gap between lab-based investigation and coaching practice, as reflected in Farrow et al. (2017) who discussed the need for the development of applied research in the field.

By adjusting WMT dosage to match action-based criteria and adjusting the LSPT to incorporate controlled and/or selective attention, it is suggested that future research will more accurately investigate the application of WMT to football training. Future research should develop the WMT and LSPT used in this study to include these changes and apply the intervention to a larger sample. It is anticipated that such research would provide a clearer context to the lack of effect of WMT on skill performance found in the results here, which contrasted with the research hypothesis.

6.5 Conclusion

This study was an application of WMT to a football skill specific test (the LSPT) in the form of a training intervention and follows on from qualitative research assessing the viability of applying WMT within Football Coaching pedagogy. The results of this study showed that the use of WMT in this study had little impact on performance and point to potential methodological issues in the use of WMT in the context of the LSPT. Future research should take the methodological findings of this research into account, whilst investigating a larger sample. It remains possible that WMT influences skill performance in football, but current methods do not yet allow a comprehensive investigation of this possibility.

6.6 Practical Implications

Future research involving the LSPT should incorporate a selective and/or controlled attention element to engage working memory and more accurately reflect the demands of skilled performance in football. The integration of WMT into Football Coaching needs further research from both prescriptive and applied perspectives, the results here do not dismiss the idea that WMT or similar methods could be used to enhance domain-specific cognitive ability in football by improving the underlying constructs of skilled performance.

Chapter 7

Study 3: WMT used with a combination of the LSPT and the Stroop Task influences skill performance in youth football players

7.1 Introduction

Working memory is described as a system responsible for the temporary storage and manipulation of information (Baddeley, 2003; Buszard and Masters, 2017; Farrow et al., 2017), with limited capacity varying between individuals (Baddeley et al., 2011; Just and Carpenter, 1992), that is linked to facilitating decision making processes. Working memory is a supporting component of perceptual-cognitive expertise (Farrow et al., 2017), which has been discussed as a differentiating factor between experts and non-experts in team sports (Verburgh et al., 2014) , with consequential functions of perceptual-cognitive ability, such as motor inhibition (Cona et al., 2015) and visual search (Voss et al., 2009) also shown to differentiate experts from non-experts.

Motor inhibition has been shown to differentiate experts from non-experts in soccer (Verburgh et al., 2014), with similar results in fencing (Di Russo et al., 2006), baseball (Nakamoto and Mori, 2008) and tennis (Wang et al., 2013), and describes how an athlete can suppress one motor response in response to changes in the competition environment (Voss et al., 2009). The ability to inhibit responses requires activation in working memory (Buszard and Masters, 2017) alongside other perceptual-cognitive processes. It is therefore desirable for athletes to execute perceptual-cognitive processes with maximum efficiency in order to prevent an overload of working memory. An overload of working memory can lead to skill breakdown, which can be understood as a “Choking” effect (Bijleveld and Veling, 2014). An alternative state to “Choking” is “Flow”, which is characterised by a feeling of automacity during performance (Dietrich, 2004) and associated with the correctly loaded and efficient use of working memory. Therefore, it is desirable to develop athletes who can efficiently use working memory during performance, a capability that may be enhanced by WMT that develops the underlying neurological structures (Dahlin et al., 2008; Loosli et al., 2011) that support working memory function.

Previous attempts to train perceptual-cognitive ability in sport have been highlighted by two issues, the first, that lab based exercises were impractical for use in training (Gabbett and Masters, 2011) due to either a lack of specificity or perceived relevance, the second, that dual tasking methods have only served to occupy working memory during action (Jackson, 2006), as opposed to training the system itself. Despite these problems, the investigation of dual tasking has some notable results, including gains in cognitive ability of up to 50% (Faubert and Sidebottom, 2012) in skilled athletes, providing evidence that there may be merit in investigating methods of cognitive training. The second issue, regarding the occupation of working memory as opposed to the active training of working memory, can be addressed by WMT. WMT uses tasks that require the temporary storage and manipulation of information, used to systematically load working memory (Atkins, 2011) during action. WMT has been researched in non-sport contexts, showing improvements in plasticity and performance on trained and transfer tasks (Takeuchi et al., 2011) with the most consistent results coming from adaptive training (Bastian et al., 2013) with a distributed frequency (Penner et al., 2012).

The LSPT has been used to assess skill performance in footballers, with early study validating the test using elite and non-elite male and female football players (Ali, 2011). The test was designed with the purpose of simulating the physiological, motor skill and decision-making demands of football. However recent work questions the LSPT from both a specificity (Serpiello et al., 2017) and perceptual-cognitive (Study 2) point of view. The specificity of the LSPT to match performance has been tested by comparing LSPT results to objective match performance data, finding that the LSPT results had poor validity when compared to match data (Serpiello et al, 2017). From a perceptual-cognitive perspective, Study 2 in this research questioned whether LSPT performance required use of controlled and/or selective attention as part of a decision-making process that would load working memory, as would happen when performing in a match situation. This study addresses the perceptual-cognitive issue by using the novel combination of the LSPT with the Stroop test (Kane and Engle, 2003), where participants are asked to recognise the colour a word is printed in, with the word being the name of a different colour, for example, the word "blue" printed in red. The Stroop test requires the use of controlled/selective attention mechanisms that have been associated with the central executive of working memory (Vandierendonck, 2014) with a correlation between working memory capacity and Stroop test performance (Ahmed and de Fockert, 2012). The Stroop test has been used recently to induce mental fatigue prior to LSPT performance in order to test the impact of mental fatigue on skill performance (Smith et al., 2017). The Stroop test makes working memory use a requirement of the LSPT, which was in doubt previously, consequently helping the LSPT to replicate match performance more accurately. The Stroop test requires participants to inhibit implicit responses when responding to the colours or words in the test, providing a simulation of the use of inhibition, a marker of skilled performance and the efficient use of working memory.

The aim of this study was to test the impact of a minimum WMT training dose on performance of the combined LSPT-Stroop Task, whilst also investigating the application of the intervention methods, specifically, the use of the Stroop task and accuracy-based changes in WMT difficulty. This study hypothesised that within the context of a combined LSPT-Stroop test, a minimum training dose of WMT would create a greater improvement in skill performance than LSPT-Stroop training without WMT.

7.2 Methods

This study used an experimental approach that included both pre-post-test data and time-series data to analyse the effects of the intervention and the changes in performance that contributed to those effects. The intervention took place over seven sessions of training, distributed over a four-week period of training and using a minimum WMT dose of fifteen minutes of training, which involved three LSPT-Stroop trials with full recovery in between. The training period was selected to provide a comparison with the study detailed in Chapter 6, allowing investigation of the impact of using STROOP as part of the intervention. The participants were split randomly into Experimental, Active Control and Passive Control groups. The results of the pre and post-test data were analysed using paired samples in addition to time-series data recorded over the course of the intervention. Post-hoc analysis was used to assess effect sizes between the Experimental Group and Active/Passive Control groups whilst changes in WMT difficulty were also recorded.

7.2.1 Participants

Participants in this study were 28 competitive (regional school competition) male youth football players aged 14-15 (*M=14.5)*, divided into experimental and Active/Passive Control groups. The Experimental Group was selected during the intervention, as the participants needed to perform the test within an accuracy benchmark before starting WMT. In the future, complete randomisation of the sample with lower ability participants removed is recommended. The Experimental Group completed 7 fifteen-minute sessions of WMT combined with the LSPT-Stroop task with a minimum two days break in between each session over a period of 4 weeks. The Active Control group completed 7 fifteen-minute sessions of the LSPT-Stroop task with a minimum two days break in between each session over a period of 4 weeks. Both groups completed a pre-test and post-test immediately before and after the intervention. All participants agreed voluntarily to participate in the study, which was approved by the Human Ethics Committee at the University of Canterbury.

7.2.2 Procedure

The participants were required to complete the pre-test two days before the start of the intervention. The pre-test required the participants to complete the LSPT-Stroop test twice, with the best scores for Completion Time, Penalty Time and Overall Time recorded. The post-test was conducted two days after the final session of the intervention, repeating the protocol from the pre-test. Best scores were used instead of the mean score to account for any learning effect or changes in speed or accuracy between tests. Participants were unaware that the best scores were recorded for speed and accuracy and were instructed to complete the test as quickly and accurately as possible at every attempt, aiming for the best score in Overall Time. Throughout the intervention, the time-series data was collected by recording all scores and selecting the best Completion Time, Penalty Time and Overall Time achieved in each session. The Experimental Groups progression in WMT difficulty was also recorded throughout the intervention.

The LSPT and the Stroop Test

The LSPT (refer to Image 6.1) was used to assess football passing skill. The test involves the completion of sixteen passes over different distances (long or short distance) to four different coloured targets placed on four benches. The targets were set up using randomly generated trials. The Stroop task (Kane and Engle, 2003) was integrated into the LSPT using the coloured targets - each target featured coloured text that spelt the name of a different colour. The participants were asked to pass to the colour that the text was written in, as opposed to the meaning of the text itself. The targets were changed for each training session to ensure that participants had to use controlled/selective attention to locate each target, as opposed to simply remembering where each colour was located. The speed of the participants was measured by recording the time the participants took to complete the test, whilst accuracy was measured by recording errors such as passing to the wrong target or missing the bench (5s), missing the target (3s), handling the ball (3s), hitting a cone with the ball (2s) or passing the ball outside of the designated area (2s). If a participant hit the small strip in the middle of each target, this was recorded as a bullseye and 1s was removed from the participants time. Image 1 below shows the LSPT and its relevant dimensions.

WMT

WMT was integrated into the LSPT using an N-back task, where participants had to pass to a coloured target that was N places back in the order of colours called out by the instructor. The test started with the researchers calling out a series of N colours before the participants commenced the test, ensuring that the entire test was completed under a WMT load.

The difficulty level of WMT corresponded to the magnitude of N on the N-back task and was adjusted based on the accuracy of the participants. Provided the LSPT was completed in under sixty-five seconds, the difficulty was adjusted up one level if a participant made less than four errors, left constant if a participant made between four and eight errors, and moved down one level if a participant made more than eight errors. This was based on the algorithm for WMT difficulty (von Bastian and Oberauer, 2013) and adjusted to the sixteen actions required on the LSPT. The sixty-five second limit for speed was an arbitrary figure, based on the overall ability level of the participants that mediated the potential for players to complete the test very slowly to increase accuracy. For reference, the target completion time on the LSPT is described as forty-three seconds (Ali, 2011; Ali et al, 2008), but these papers had access to more highly-skilled participants.

7.2.3 Statistical analysis

Data analysis was performed by first looking for significant differences between pre- and post-test results, then by comparing effects between groups. The analysis sought to understand any significance or effects sizes by analysing time-series data to gain insight into how impacts of the intervention may have occurred. Pre-test and post-test data were analysed using a paired-samples t-test to measure significant differences within groups. Cohen's *d*, Glass' Δ and Hedges' *g* were used describe effect sizes between the Experimental Group and Active/Passive Control groups whilst accounting for potential biases caused by SD differences and/or differences in sample size. The magnitude of effect sizes was noted based on the levels found in Sullivan and Feinn (2012). Time-series data was graphed to map how performance was affected between the pre-test and post-test. Changes in WMT difficulty for the Experimental Group were collected with the Mean Max Difficulty, Mean Session Difficulty and Mean Session/Trial Difficulty Progression calculated. Collecting WMT difficulty changes helped to investigate whether WMT was being administered appropriately during the intervention.

7.3 Results

Pre and post-test data were analysed first for significance in paired t-test results within groups, then effect size between groups.

Table 7.1 Mean ± for Pre/Post LSPT Results

	Completion Time (s)				Penalty Time (s)				Overall Time (s)			
	Pre-Test		Post-test		Pre-Test		Post-test		Pre-Test		Post-test	
Active Control (n = 10)	58.52	±5.3	58.62	±4.4	15.00	±10.6	18.40	±9.7	74.94	±14.7	77.86	±8.7
Passive Control (n = 8)	56.28	±7.8	56.49	±5.7	30.75	±11.0	31.00	±10.8	89.08	±11.7	89.03	±13.1
Experimental (n = 10)	50.90	±3.8	53.83*	±5.2	7.50	±9.4	1.30	±6.1	59.10	±12.5	57.32	±7.7

*Significant difference
(p = < 0.05)

Table 7.2 Mean differences in Penalty, Completion and Overall Time within groups

	Comp. Time Difference			Pen. Time Difference			Overall Time Difference		
	Mean	SD	*p*	Mean	SD	*p*	Mean	SD	*p*
Active Control (n = 10)	0.10	±8.7	0.972	3.40	±12.4	0.408	2.92	±13.6	0.515
Passive Control (n = 8)	0.21	±4.3	0.896	0.25	±3.6	0.850	-0.05	±5.8	0.983
Experimental (n = 10)	2.92	±4.1	0.049*	-6.20	±9.7	0.074	-1.79	±10.5	0.605

*Significant difference
(p = < 0.05)

There was a significant difference for the Experimental Group between the pre-test Completion Time (M=50.9, SD=3.8) and post-test Completion Time (M=53.83, SD=5.2), $t_{(9)}$= 2.270, p=0.049. This result suggests a decrease in speed in the Experimental Group associated with the

WMT dose. Table 7.3 displays the effect sizes between the Experimental Group and the Active/Passive Control groups.

Table 7.3 Effect sizes of Pre/Post Mean Differences between Experimental Group and Active/Passive Control

		Completion Time					Penalty Time					Overall Time				
		MeanDiff	SDAv	*d*	Δ	*g*	Mean Diff	SDAv	*d*	Δ	*g*	Mean Diff	SDAv	*d*	Δ	*g*
Experimental Group (n = 10)	AC (n = 10)	2.82	±6.41	0.44*	0.32*	NA	9.60	±11.04	0.87 ***	0.78 **	NA	4.70	±12.08	0.39*	0.35*	NA
	PC (n = 8)	2.71	±4.20	0.65 **	NA	0.65 **	6.45	±6.65	0.97 ***	NA	0.84 ***	1.74	±8.19	0.21*	NA	0.20*

*small effect 0.2, **medium effect 0.5, *** large effect 0.8, (Sullivan and Feinn, 2012)

Effect sizes of the mean differences between groups showed small effect between the Experimental Group (n = 10) and Active Control (n = 10) for Completion Time (d=0.44, Δ=0.32) and Overall Time (d=0.39, Δ=0.35), whereas there was a large effect in Penalty Time (d=0.87, Δ=0.78). Between the Experimental Group and the Passive Control, a small effect was found for Overall Time (d=0.21, g=0.2), medium effect was found for Completion Time (d=0.65, g=0.65) and a large effect was found for Penalty Time (d=0.97, g=0.84). The results suggest that using WMT as an addition to normal training can improve skill accuracy and overall performance, with a negative impact on speed. It is not known if the negative impact on speed could be addressed by further training without increases in difficulty, that question would have to be addressed in a longitudinal study. The results reflect the idea of a speed-accuracy trade-off related to mental fatigue.

Throughout the course of the intervention, the best scores in Completion Time, Penalty Time and Overall Time were taken from each session (including the pre-test and post-test) to detect fluctuations in performance in the Experimental and Active Control groups. In addition, the time-series data allowed this research to understand the comparative journey of the Experimental and Active Control groups between the pre-test and post-test. The figures below show the changes that occurred throughout the study:

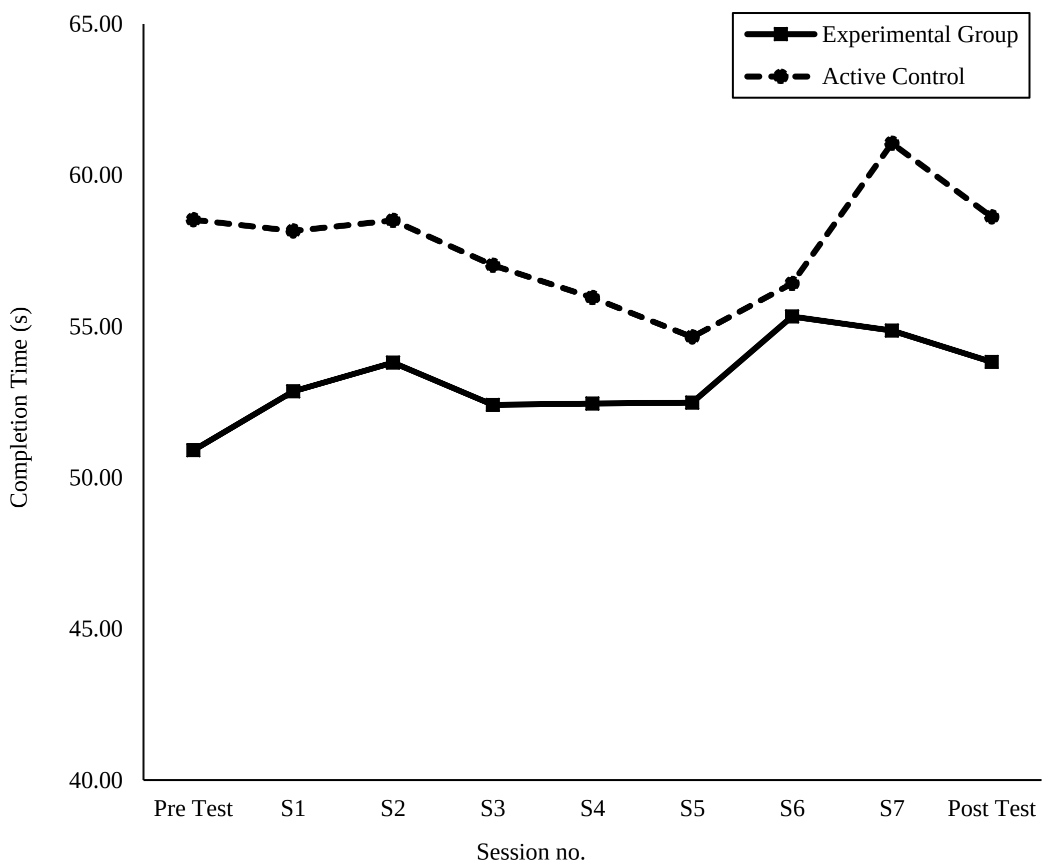


Figure 7.1 Changes in Mean Best Completion Time throughout the intervention

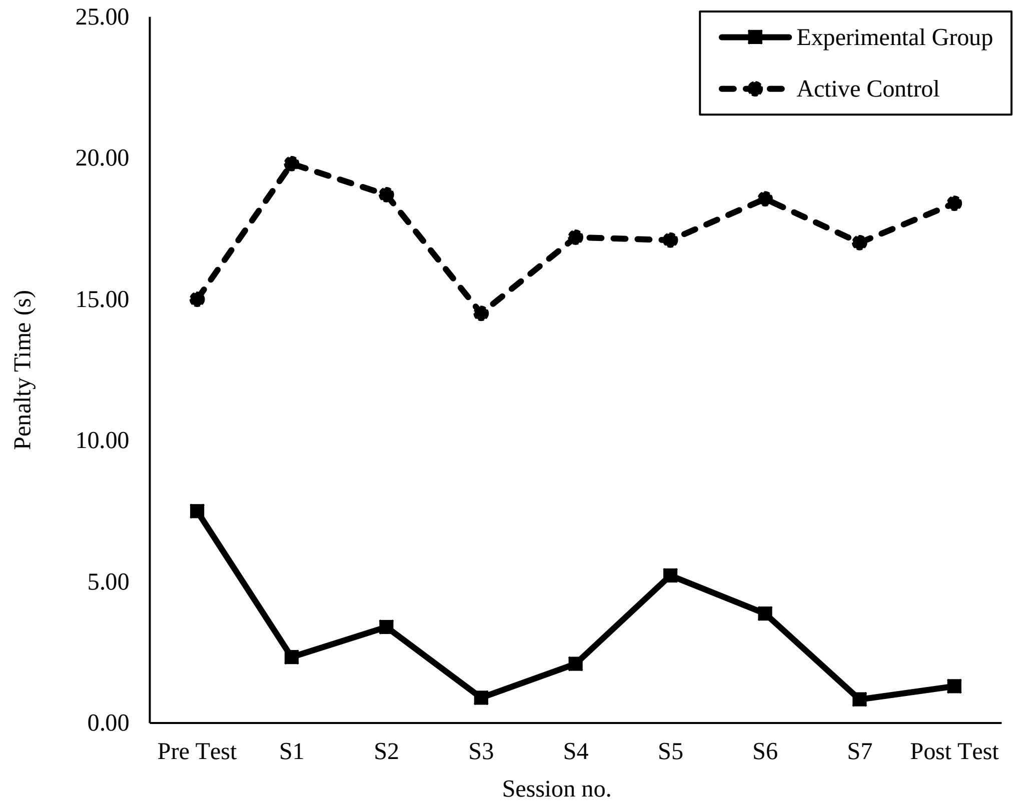


Figure 7.2 Changes in Mean Best Penalty Time throughout the intervention

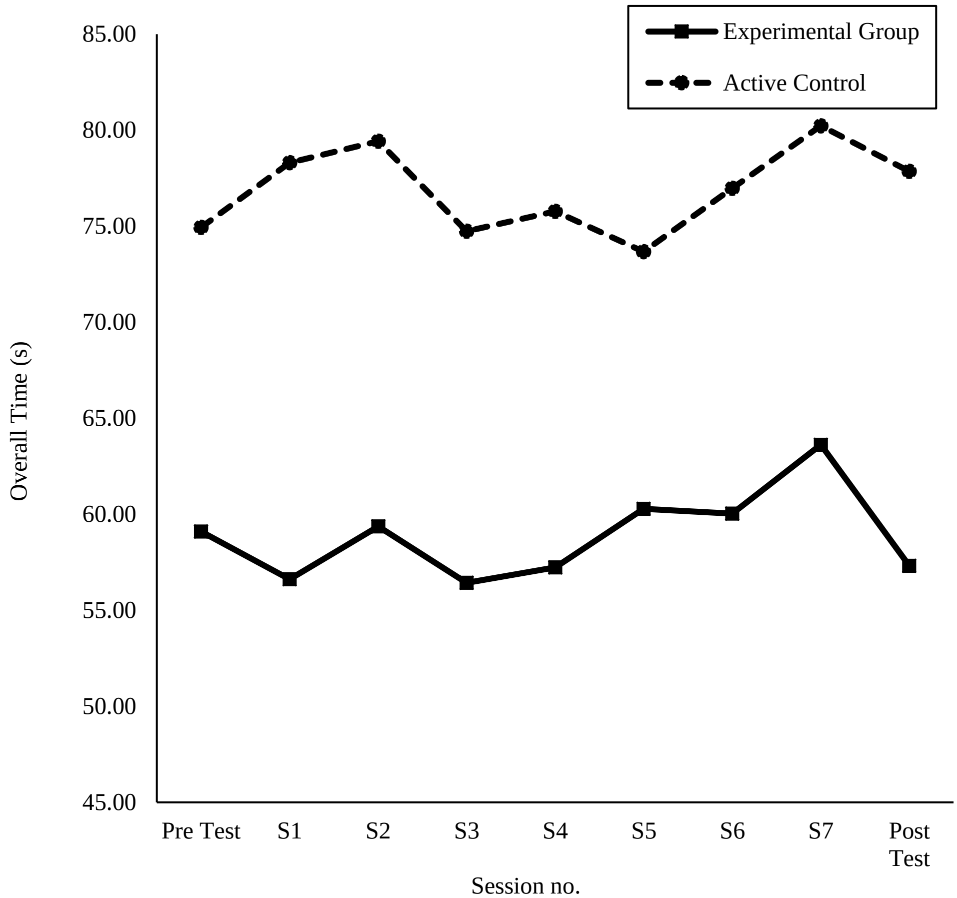


Figure 7.3 Changes in Mean Best Overall Time throughout the intervention

The time-series data demonstrates changes in performance that may reflect changes in how actions were performed early in the intervention, the impact of increased WMT later in the intervention, and the adaptation following WMT between the final training session and the post-test.

Changes in WMT difficulty throughout the study were recorded to assess changes in working memory performance during the intervention, supplementing the analysis of skill performance and validating a degree of replication of lab-based WMT. Table 7.4 displays the session-by-session change in N-back difficulty achieved by the Experimental Group.

Table 7.4 Mean ± N-back Difficulty by session no.

	N-back Session 1	N-back Session 2	N-back Session 3	N-back Session 4	N-back Session 5	N-back Session 6	N-back Session 7
M	0.33±0.71	1.11±0.6	1.50±0.85	1.90±0.88	2.33±0.87	2.25±0.71	2.50±0.55

Table 7.5 displays descriptive statistics of the changes in N-back difficulty for the Experimental Group. The “N-back Max” value reflects the highest level a participant completed, which in some cases was followed by the participants dropping down a level in difficulty, creating a slight difference between the N-back Session 7 result in Table 7.4 (M=2.5, SD=0.55) and the N-back Max value displayed in Table 7.5 (M=2.7, SD=0.8).

Table 7.5 Analysis of changes in N-back difficulty

(n = 10)	Sessions	Trials	N-back Start	N-back Max	N-back Mean	N-back Progression/Session	N-back Progression/ Trial	N-back Difference
M/SD	6.10±0.9	18.30±2.6	0±0	2.70±0.8	1.66±0.6	0.45±0.1	0.15±0.05	2.70±0.8

The results indicate that the Experimental Group (n=10) advanced from a base level of N-back difficulty (M=0, SD=0) to higher difficulties (M=2.7, SD=0.8) during the intervention with a mean trial difficulty of 1.66±0.6. The difficulty progressions in each session (M=0.45, SD=0.1), which were also measured in trials (M=0.15, SD=0.05) suggest a consistent improvement between participants, relatively independent of ability, during each session. The results appear to indicate that the use of a minimum dose (Sessions M=6.1, SD=0.9; Trials M=18.3, SD=2.6) of adaptive WMT in the Experimental Group yielded improvements in domain-specific working memory performance concurrent to changes in skill performance versus the Active and Passive Control. This suggests that using WMT as a dual task could develop working memory concurrently to skill performance.

7.4 Discussion

The aim of this study was to investigate the impact of a minimum dose of WMT on skill performance, whilst also testing the novel LSPT-Stroop task, which introduced controlled/selective attention and motor inhibition into the LSPT, and the use of an action-based difficulty metric to prescribe WMT difficulty. This study hypothesised that within the context of a combined LSPT-Stroop test, a minimum training dose of WMT would create a greater improvement in skill performance than LSPT-Stroop training without WMT.

The results of this study show that there was a significant difference for the Experimental Group in pre-test Completion Time (M=50.9, SD=3.8) and post-test Completion Time (M=53.83, SD=5.2), $t_{(9)}$=2.270, p=0.049), small effect between the Experimental Group (n = 10) and Active Control (n = 10) for Completion Time (d=0.44, Δ=0.32) and Overall Time (d=0.39, Δ=0.35), as well as large effect in Penalty Time (d=0.87, Δ=0.78). In addition, between the Experimental Group and the Passive Control small effect was found for Overall Time (d=0.21, g=*0.2*), medium effect was found for Completion Time (d=0.65, g=0.65) and large effect was found for Penalty Time (d=0.97, g=0.84). The time-series data indicated different fluctuations in performance between the Experimental and Active Control group. The Experimental Group (n=10) advanced from a base level of N-back difficulty (M=0, SD=0) to higher difficulties (M=2.7, SD=0.8) during the intervention with a mean difficulty of 1.66±0.6, demonstrating a consistent change in WMT difficulty within the group (N-back progression/trial; M=0.45, SD=0.1).

The results of the pre and post-test indicate that the use of WMT in the Experimental Group did create a change in performance, and despite the limited statistical significance of the results (likely related to the sample size), the effect sizes found between the Experimental Group and Active Control do tentatively support the hypothesis of this study. In particular, the large effect size found in Penalty Time does make sense in the context of the speed-accuracy trade-off associated with the LSPT under mental fatigue (Smith et al., 2017). The WMT dose would have induced a degree of mental fatigue throughout the intervention with appropriate rest between training sessions, potentially resulting in a supercompensation effect where participants found the exercise less fatiguing, and therefore performed more accurately, albeit at a similar speed. This is further supported by the small effect size in completion time between the Experimental Group and Active Control, in addition to the significant effect found for Overall Time between pre and post-test for the Experimental Group. Further research with a longer intervention and greater sample size would help to improve understanding of the relationship between WMT and skill performance.

The time-series data for the Experimental Group showed converse changes in speed and accuracy between the pre-test (Completion Time M=50.9, SD=3.75; Penalty Time M=7.5, SD=9.36) and session 3 (Completion Time M=52.41, SD=5.1; Penalty Time M=0.9, SD=6.3), with a small change in overall performance between the pre-test (M=59.1, SD=12.5) and session 3 (M=56.43, SD=10.79). These changes suggest that participants could have been forced to perform actions more implicitly (greater stability/accuracy under stress; per Masters, 1992, Masters et al., 2008), with retrieval of implicit skills slowed by the impact of WMT on inhibition processes from the Stroop test. However, as the WMT load was smaller in the first few sessions, the result might alternatively indicate that the load on working memory was appropriate for inducing a Flow state, where working memory capacity was used enough to prevent a drift in attention but not to the point of overload and skill breakdown. In contrast, the Active Control scores remained relatively similar between the pre-test (Completion Time M=58.52, SD=5.3; Penalty Time M=15, SD =10.6; Overall Time M=74.94, SD=14.72) and session 3 (Completion Time M= 57.02, SD=4.11; Penalty Time M=14.5, SD =9.58; Overall Time M=79.43, SD=9.39).

This idea of fully engaging working memory capacity is supported further by the changes in performance between sessions 4 and 7, where Completion Time stabilised in sessions 4 (M=52.45, SD=6.05) and 5 (M=52.48, SD=7.42) before increasing through to session 7 (M=54.87, SD=6.73) whilst Penalty Time increased up to session 5 (M=5.22, SD=10.7) before decreasing to a consistent level in session 7 (M=0.83, SD=2.48), Overall Time increased in each session up to session 7 (M=63.62, SD=8.23). When considering the increase in N-back difficulty between session 4 (M=1.5, SD=0.85) and session 7 (M=2.5, SD=0.55) and the max N-back difficulty reached (M=2.7, SD=0.82), the changes in Completion Time, Penalty Time and Overall Time for the Experimental Group could be explained as a response to an increase in WMT load through session 4-7. This is further supported in the post-test results, where Overall Time reduced from M=63.62 (SD=8.24) to M=57.32 (SD=7.72) when the N-back task was removed, which suggests a compensation effect following the WMT dose beforehand.

In contrast, the Active Control only displayed a noticeable change in Completion Time between session 4 and the post-test, increasing from M=55.96 (SD=7.03) to M=61.05 (SD=6.31) before recording M=58.62 (SD=4.34) in the post-test whilst penalty time and overall time stayed relatively stable for the duration of the study. This change may have been a result of the intervention becoming monotonous for the participants, which suggests that future studies should consider a placebo dual task in combination with recording monotony for the two groups to account for such a change. It is also possible that the Active Control did not use all their working memory capacity to complete the task, therefore creating a chance that their attention could drift (per Dietrich, 2003; 2004) to a greater degree than the Experimental Group, which could have also contributed to a decrease in performance. The fluctuations in results may have reflected and upper and/or lower limit in scoring for the Active Control group. This study also found that the use of WMT was replicated in the context of the LSPT-Stroop, as the use of the N-back appeared to yield a consistent improvement in the players with a relatively tight distribution in session difficulty progression (M=0.45, SD=0.1).

The time-series findings may give some guidance on how WMT changes performance and how it may be periodised, as these results reflect a progressive overload-type sequence of loading, recovery and compensation. In addition, the N-back difficulty results may give guidance on how WMT difficulty could be prescribed in long-term planning process, as the results indicate a consistency in progression from WMT that may be independent of an individual's ability, although it would be assumed that progression would have to slow eventually at higher levels not tested here. The apparent progressive overload sequence and consistent change in N-back difficulty may indicate a possibility to prescribe WMT with a degree of predictability in performance improvement, provided principles of volume and frequency (per Chapter 2) are respected. In some part this reflects the conceptualisation in Chapter 3, demonstrating how WMT could be periodised within football training. Future work would be required to investigate these issues further.

There are also methodological findings emerging from the study. Firstly, the LSPT-Stroop needs improvement to increase the difficulty of the Stroop task, but may already be a better simulation of match demands than the LSPT alone. This is due to increased demands on controlled/selective attention, and therefore working memory, which is reflected in the changes in both working memory and skill performance found in the results. In this study, the Stroop targets were changed in each training session, and the participants were asked to pass to the target with the correct coloured text. This was limited by the equipment available, and future work should explore how both the Stroop task and target location could change during the test to mitigate the chance of adaptation to one form of Stroop task and/or simply remembering the target locations. Improving the LSPT-Stroop test may help in finding clearer results (increased significance and larger effect sizes) in future longitudinal studies with larger sample sizes. It would be interesting to investigate the effects of WMT on an LSPT-Stroop intervention where the target location/selection criteria change following every pass.

Finally, the use of an action-based metric with an arbitrary upper speed limit to adjust WMT difficulty appears to be more appropriate than using an overall performance metric alone (as used in Study 2) as the results show a consistent change in N-back difficulty that appears to be less variable than changes in LSPT performance. Future work should explore how individualising the upper speed limit could affect WMT difficulty changes. There is the possibility that an arbitrary upper speed limit led some participants to perform at a slower speed than they were capable of, in contrast to speed improvements in participants for which the upper speed limit may have been more appropriate to their ability. This may have limited the changes in performance observed during the study.

7.5 Conclusion

This study was an application of WMT dose to a test simulating skill performance demands in football (the LSPT-Stroop). The results of this study indicate that WMT influenced skill performance both during and post-intervention, affecting both speed and accuracy and consequently overall performance in comparison to the control groups. Participants also recorded a consistent change in performance on WMT tasks that appear to be independent of ability. It seems that using WMT as a dual task may develop working memory and skill performance, increasing activation for explicit processes that guide and adapt action whilst encouraging the use of implicit skills in the execution of actions. The Stroop test appears to be a useful addition to the LSPT, incorporating contextual interference, inhibition and controlled/selective attention, but does need to be developed for future tests. An action-based protocol appears to be suitable for adjusting WMT difficulty, however further considerations need to be given to managing the speed of actions, due to variances in individual ability.

This study is limited by the variance in ability and the size of the sample created by the context of the research. The variance in the ability of participants affected the ability to randomly sample, as it was clear participants need to be able to perform the LSPT relatively accurately in order to complete the LSPT-STROOP with WMT. In addition, the ability of participants may have impacted on both the effect sizes and significance of results – for example, a less competent participant may improve very quickly in comparison to a skilled participant in terms of LSPT score, as there is a greater opportunity to make immediate improvements in performance. Longitudinal studies with a larger and more consistent sample are therefore needed to validate any claims here.

7.6 Practical Implications

It appears that WMT use may impact the development of skill in football but needs correct periodisation (e.g. action-based metrics, distributed volume), as well as practitioner understanding of the observable effects on participants during training due to changes in explicit/implicit processes. Using the Stroop test to introduce controlled/selective attention and inhibition to the LSPT potentially strengthens the validity of the LSPT, despite further work being needed to improve target location/target selection criteria in the test.

Chapter 8: Thesis Discussion

This Chapter begins by describing the research process, then placing the discussion in the context of existing literature and gaps in knowledge. This is followed by a discussion of the research limitations and the scope for future work. Chapter 8 ends by concluding the discussion and closing the thesis.

8.1 Research aim, questions and key findings

This research began with an aim to determine how training to develop the structures supporting perceptual-cognitive skill (Perception, Decision Making and Execution) in the context of football could be achieved. Following this aim, the literature highlighted the following gaps in knowledge regarding the function, role and development of perceptual-cognitive skill in sport and consequently, Football Coaching:

- Limited domain-specific and practically applicable perceptual-cognitive training methods for Football Coaching.
- A lack of systemisation and periodisation for perceptual-cognitive training and the use of dual training tasks that occupied working memory but had not been shown to develop the system itself.
- No conceptualisation of how WMT could be periodised and applied within a Football Coaching model and Football Coaching practice.
- No research that implemented WMT in Football Coaching practice both collaboratively and as a new training methodology.

- A lack of intervention studies assessing the impact of WMT on skill performance (later work also highlighted issues in the validity of skill tests in football).
- Evidence of concurrent improvements in working memory performance and the application of motor skills following a WMT intervention.

These gaps in knowledge were addressed with a sequence of research questions, presented in Table 8.1 on the following page, with the sequence of work undertaken reported in the thesis then described in brief.

Table 8.1 – The Research Process and Key Findings

	Research Question	Chapter	Format	Key Findings
Theorising	What form of training would be suitable for developing the structures supporting Perception, Decision Making and Execution in football?	2 (2.1)	Literature Review: Working Memory and Sports Performance	Understanding expert performance in sport, perceptual-cognitive skill and the function and underpinnings of working memory.
		2 (2.2)	Systematic Literature Review: WMT	Identification of training principles for prescribing effective WMT
	How could WMT be systemised and conducted in the context of Football Coaching?	3	Theorising and Model Creation: WMT in Football Coaching methodology (Game Training Model)	Developed a model of application for WMT principles within the Game Training Model
		5	Study 1: Applying WMT in Football Coaching using PAR	Pedagogical guidelines and technological advances required for the practical application of WMT principles within the Game Training Model
Investigation	How does WMT impact skill performance in football?	6	Study 2: Does a minimum dose of WMT during football skill performance impact results on a football skill test?	Suggestion of WMT impact on skill performance and methodological changes in testing and prescription required for more effective investigation
		7	Study 3: WMT used with a combination of the LSPT and Stroop Task influences skill performance in youth football players	Evidence that WMT influences skill accuracy and speed, the LSPT-Stroop provided a test that more closely replicated working memory use in match performance

Systematic Literature review – WMT

A systematic literature review of WMT was performed to investigate WMT as a training method. The systematic literature review used a clinical methodology that involved a literature search and quality appraisal (per Wright et al., 2007) followed by a tabulation for analysis. The review included studies that investigated the prescription of WMT, the impact of WMT on trained and/or transfer tasks and neurological adaptation, whilst covering a range of populations throughout the lifespan (from child to old-old adults). The studies examined in the literature review suggested the existence of training principles for prescribing WMT, research following the review adhered to the training principles in the research design when prescribing WMT.

A conceptualisation of the integration of WMT principles into Football Coaching

Based on the literature in Chapter 2, the principles of WMT were examined alongside the Game Training Model, which accounts for the structure and periodisation of football exercises with reference to a given Playing Model. The outcome was that WMT could be used during TT sessions on G+3 and G-2 each training week. In individual cases, based on load monitoring, the training week could be individualized - making it possible that WMT could be used during REC or TTA sessions on G+1/2 and/or G-1. WMT could occur within the Passing Practice and Positioning Game to improve player actions relating to a team task - *once* an effective method for integrating WMT into Football Coaching had been investigated and developed further.

Study 1: Applying WMT in Football Coaching using PAR

The purpose of the PAR study in Chapter 5 was to investigate how WMT could be integrated into Football Coaching practice. This was achieved by using a PAR methodology that created a forum for collaboration with the participants. The research was carried out in three cycles of planning, data collection and reflection that triangulated researcher, coach and athlete perspectives through observational notes, video analysis and semi structured interviews. Each cycle was aimed at advancing practice-based findings from the cycle before, with input from all perspectives considered. The research data was analysed thematically, with findings categorised to provide clarity and structure to the findings.

The research solved and highlighted pedagogical and technical considerations for future research and the integration of WMT into Football Coaching, whilst it appeared that the impact of using WMT in the lab was replicated to a degree in the training sessions. Pedagogies that rely on implicit feedback and learning appear to be most suitable for WMT to be used, provided participants have been given the opportunity to adapt to the training methods. Significant work is required to develop technology that would make WMT a feasible tool for coaches to use, as the application of WMT in Football Coaching seems to require automated, individualised and adaptive WMT that can be completed with a non-verbal response. WMT could be used by coaches to systematically develop an implicit Playing Model whilst simultaneously developing working memory to improve the ability of players to adapt the Playing Model to novel and complex situations. Chapter 5 also demonstrated the strength of using a qualitative approach (PAR) to investigate the use of new methods in coaching, as the themes and categories that emerged from the research were guided by collaboration between researcher, coach and athlete.

Study 2: Does a minimum dose of WMT during football skill performance impact results on a football skill test?

This study measured the effects of a WMT intervention on football skill performance, using the LSPT. This Passive and Active Controlled study utilised a pre/post-test and time-series design with measurements of speed, accuracy, overall performance and working memory performance analysed using paired samples, effects sizes, and time-series over a four-week LSPT training intervention. Players were required to complete the test whilst performing a WMT protocol of N-back tasks. The study found a significant difference in accuracy ($p=0.03$) when comparing pre-test and post-test results within the Experimental Group. In measures of speed and accuracy there were small effect sizes between the Experimental Group and Active Control (*M* Effect=0.44, *M* Effect=0.22), large effect sizes between the Experimental Group and Passive Control were found for speed (*M* Effect=0.98) whilst small effect sizes were found for accuracy (*M* Effect=0.43) and overall performance (*M* Effect=0.28). Time series data indicated an effect on accuracy between the Experimental Group and Active Control during the intervention. The data also showed limited improvement in performance on the working memory tasks. The findings suggest that more refined methods of applying WMT to football skill protocols are required, whilst the LSPT may not require the same working memory use as playing and training competitively. More accurate action-based dosing methods of WMT, as well as possible changes to the LSPT, are discussed as future directions for research.

Study 3: WMT in a modified LSPT impacts skill performance in youth football players

This study measured the effect of a WMT intervention on performance of a modified LSPT-

Stroop test, designed to incorporate selective and/or controlled attention into the LSPT, simulating the use of working memory during match performance. The test also featured a novel method for adjusting the difficulty of WMT based on action accuracy. This Passive and Active Controlled study utilised a pre/post-test and time-series design with measurements of speed, accuracy, overall performance and working memory performance analysed using paired samples, effects sizes, and time-series over a four-week intervention. The study found a significant difference in pre/post-test Completion Time for the Experimental Group ($p=0.049$). In addition, small effect sizes were found between the Experimental Group and Active Control for Completion Time ($d=0.44$, $\Delta=0.32$) and Overall Time ($d=0.39$, $\Delta=0.35$), as well as large effect in Penalty Time ($d=0.87$, $\Delta=0.78$). Between the Experimental Group and the Passive Control, small effect was found for Overall Time ($d=0.21$, $g=0.2$), medium effect was found for Completion Time ($d=0.65$, $g=0.65$) and large effect was found for Penalty Time ($d=0.97$, $g=0.84$). Time series data comparing the Experimental Group and Active Control indicated a positive change in accuracy and overall time for the Experimental Group balanced with a negative change in speed. The time series data also suggested a progressive overload process in the intervention. WMT difficulty data indicated a consistent improvement in WMT performance that was independent of skill level. The results of the research suggest that using WMT as a dual task could be a method to develop skill performance and working memory performance simultaneously, which could affect coaching methods. Research with a larger sample size and a comparative study between the LSPT and LSPT-Stroop to assess match validity, plus refinements to the LSPT-Stroop test are recommended.

8.2 Relationship between the literature and key findings

Perceptual-cognitive skill is a differentiating factor between skilled and lesser-skilled athletes (Ward and Williams, 2003; Mann et al., 2007; Voss et al., 2009; Vestberg et al., 2012) and has been shown to have a relationship with greater efficiency in working memory activation (Mann, 2007; Voss et al., 2009; Pruna and Bahdur, 2016). Greater efficiency is referred to as “economy of attention” and “economy of action” (Gabbett and Masters, 2011) and has close links with the use of procedural knowledge (Maxwell et al., 2003; Jackson et al., 2006), implicit motor learning (Masters, 1992; Masters et al. 2008; Poolton et al., 2008) and states of hypofrontality associated with Flow (Dietrich, 2004). The application of perceptual-cognitive skill in Football Coaching (Game Training Model – Cross et al, 2013) is understood as three stages – Perception, Decision Making and Execution (Cross et al., 2013; O'Connor et al., 2017) which are supported by the function of working memory (Pruna and Bahdur, 2016) and its associated neurological structures (Dietrich, 2004; Knudsen, 2007).

Within Football Coaching, the processes of Perception, Decision Making and Execution are developed by replicating match demands accurately (Owen et al., 2004; Jones and Drust, 2007; Dellal et al., 2011) and using - amongst a range of athlete-centred pedagogies - constraint-based pedagogy (O'Connor, 2017; O'Connor et al., 2018), task-based pedagogy (Cross et al., 2013) and/or guided discovery (Gabbett and Masters, 2011; Nash, Sproule, and Horton, 2011; O'Connor et al., 2017). Despite the existence of well documented methods by which to improve the processes of Perception, Decision Making and Execution, methods that specifically develop the neurological structures supporting these processes have been less clear, with domain-specific use (Faubert and Sidebottom, 2012) and practicality (Gabbett and Masters, 2011) an issue in the application of perceptual-cognitive training - despite evidence of improving perceptual-cognitive skill across different age groups (Ward and Williams, 2003). Targeting the neurological structures underlying Perception, Decision Making and Execution appears to be possible by using WMT, which can be systemised and prescribed with specific principles (per Section 2.2) and has evidence of improving both trained and transfer tasks (Smith et al., 2009; Brehmer et al., 2011; Loosli et al., 2011; Takeuchi et al., 2011; Brehmer et al., 2012; Schneiders et al., 2012; von Bastian and Oberauer, 2013) that are related to changes in neural efficiency (Dux et al., 2009; Jolles et al., 2013) and plasticity (Dahlin et al., 2008; Loosli et al., 2011; Takeuchi et al., 2011; Bastian et al., 2013).

To investigate the use of WMT in Football Coaching, this research used WMT as a dual task during training and/or skill performance, which provided a means of concurrently developing domain-specific implicit actions, working memory efficiency and the neurological structures underpinning working memory. These three effects are implied to different degrees by evidence in both the qualitative work in Study 1 and the quantitative work in Studies 2 and 3, where changes in skill performance occurred alongside improvements in performance on working memory tasks. Using imaging to investigate these effects on a deeper level was beyond the scope of this work, however, the literature does provide enough imaging studies involving WMT to suggest that this observation could be accurate. The evidence supporting the idea that concurrent development of skill and working memory is encouraging, as it supports the idea that WMT could be used as part of a wider training methodology to develop an implicit Playing Model, with working memory activation both developed and kept free to adapt and manipulate implicit responses relative to the situation faced. This would also need to be supported by methods that ensure working memory activation is fully focused on the task at hand, preventing processes such as daydreaming (Dietrich, 2003) from impacting performance. Achieving such a methodology could theoretically allow players to assimilate Playing Models faster than what is possible in existing training methodologies, whilst also making the Playing Model more stable and adaptable under stress. These claims cannot be investigated until the WMT methodology formulated in this research has been developed to the point where it can be applied over a season(s) of training and compared to other training methodologies. Even with further research, the application of training methodology and the development of a playing model is always subjective - dependent on the characteristics of players and the socio-cultural context of a team – and therefore it may be difficult to objectively quantify differences in application. Alternatively, qualitative research may be an alternative to investigating the use of such an approach, incorporating a collaboration of researcher, coach and athlete perspectives, as demonstrated in Study 1 of this research.

The qualitative approach in Study 1 investigated how WMT could be used in a practical coaching context, which reflected the previous effective use of action research to develop coaching practice (Evans and Light, 2008; Naslund, 2011; Pill, 2014; Clements and Morgan, 2015) . The literature demonstrated the impact of integrating the perspectives of athlete, coach and researcher to form new practice, whilst also addressing the social barriers associated with introducing new methodologies into existing practice. This research utilised a similar approach and found that the input of athletes and coaches provided insight that guided the data analysis, especially in the case of understanding the athlete’s perceptions of how WMT impacted skill performance and the impact of WMT on coaching pedagogy.

Due to the practical context of the research, the ability to collect evidence of how the WMT used in the training impacted neurological function was limited, for example, it’s difficult to use fMRI in training exercises to monitor activation. By understanding the perspective of the athletes, the research was able to investigate whether the perceived impact of WMT was consistent with suggestions in the literature, and therefore found evidence that the processing impact of lab-based WMT appeared to be transferred to practice.

From a pedagogical perspective, investigating coach perceptions allowed the research to consider the coaching behaviours and pedagogies that need to be accounted for or adjusted when using WMT, and vice versa. Specifically, athlete-centered pedagogies such as problem-solving seemed to be suited to using WMT, as in problem-solving pedagogy, participants are adapting an existing system of behaviours to solve a novel problem or situation, with coach instruction occurring during breaks in play. Use of WMT in exercises and actions that were already understood by the participants made the execution of WMT itself more effective, possibly reflecting the degree of procedural knowledge and/or implicit actions being used. In addition, during problem-solving exercises, the participants are being forced to adapt existing implicit responses to solve a problem, therefore using WMT as a dual task could increase the efficiency of the adaptation and manipulative processes themselves, in addition to forcing the retrieval and encoding of implicit actions. Overall, the process of using PAR in this research allowed the coach to contribute to how new methodology would be used in practice, whilst providing another perspective to the researcher.

Efficient use of working memory is dependent on a balance between explicit (declarative) knowledge as a top-down process in the cognitive system and implicit (procedural) knowledge as a bottom-up process from the limbic system, which can be observed as a Flow state (Dietrich, 2003, 2004). This balance is demonstratable by evidence of a hypofrontality state during Flow, where cognitive activation decreases (Dietrich, 2003; 2004) and is perhaps also characterised by an increased use of procedural knowledge or implicitly learned motor skills (Masters, Lo, Maxwell and Patil, 2008; Masters et al., 2008; Lam et al., 2009; Gabbett and Masters, 2011). The inefficient use (or overload) of working memory can be associated with an alternative – “Choking” which can be associated with a hyper-frontality state (Dietrich, 2004), where a stress response (Schmader and Johns, 2003), reinvestment (Masters and Maxwell, 2008), or distraction (Beilock, 2008) can contribute to a breakdown in the Perception-Decision-Execution chain. In addition to the two states, it has also been hypothesised that unused working memory activation could contribute to a drift in attention, as observed in actions such as daydreaming (Dietrich, 2003).

The implications of efficiently or inefficiently using working memory appeared to be observed in two ways within the time-series data collected during the intervention study in Chapter 7, where increases in WMT difficulty impacted the speed and/or accuracy of participants. Firstly, participation at a low (relative to ability) WMT difficulty demonstrated a positive change in performance when compared with performing the LSPT with no WMT load.

This suggested that the WMT load may have forced participants to use full working memory activation without overload, which would have meant their full attention would have been on the task whilst also being forced to apply implicit motor skills, which are faster and more stable (Masters et al., 2008), leading to an improvement in performance. However, without overloading working memory, it is questionable that participation at a low relative difficulty can lead to the changes in plasticity and efficiency reported in the literature. Secondly, participation at higher difficulties (relative to ability) caused a degradation in performance, which may have reflected too high an overload on working memory, potentially leading to stress, reinvestment or distraction responses when participants found the WMT difficult to complete. However, following further doses at a higher difficulty, performance did improve.

Based on the literature and the findings in Chapter 7, it seems that an ideal difficulty for creating changes in working memory is neither too low or too high, sitting at a point where working memory is overloaded enough to create a change in efficiency and plasticity but not overloaded to the point that performance breaks down. This has an implication on the prescription of WMT, which requires consistent criteria or changes in difficulty that adjusted to the ability of each individual. This idea was also reflected in the qualitative work in Study 1, where it became apparent that the use of a one-size-fits-all approach to difficulty prescription would not be appropriate when trying to use WMT within a practical setting.

8.3 How this research addressed gaps in knowledge

The literature in Chapter 2 revealed some gaps in knowledge that this research sought to address. These gaps related to perceptual-cognitive training methodology in sport (and football), the systemisation of WMT and the understanding of how WMT as a dual task could impact performance. These gaps formed the core of the research questions used and were addressed in Chapters 2-7 sequentially.

The literature demonstrated that there were limited domain-specific and practically applicable perceptual-cognitive training methods for Football Coaching. Faubert and Sidebottom (2012) commented on the challenges in taking cognitive training out of the lab and onto the pitch, including the consideration of how non-specific lab-based training can transfer into domain-specific use. Gabbett and Masters (2011) commented on how the use of dual tasking had involved tasks that were found to be impractical by coaches. These gaps were addressed in Chapters 2-5 by investigating literature on training methodology to suggest WMT training principles that could be conceptualised within a model of Football Coaching, then that conceptualisation was implemented within qualitative research (in collaboration with coaches and athletes) to understand the practical application of WMT.

The key step was looking at the problem through the lens of a football coach and addressing the practicality of the training methods by placing them within the context of a complete philosophy and system of Football Coaching (the Game Training Model). This was then backed up through a collaborative research approach, addressing the impracticality experienced by coaches by empowering coach and athlete to influence how the practical application of WMT in football was developed. This process allowed this research to understand and assess the transfer of WMT tasks to a practical setting, the pedagogical considerations when using WMT and the technological advancements that are required/need to be investigated in future to make WMT practical. At the least, there seems to be a road map towards making WMT both practical and effective for football coaches, which didn't appear to exist before this research.

Approaching this research through the lens of a coach had another benefit - the suggestion of training principles of WMT. This differs from the literature because as a coach, I look for ways to develop athletes over a long-term plan, rather than testing effects within a short-term intervention. A long-term plan requires principles of training, using the most effective iteration of a method at the most effective time, relative to competition timing. This does not mean that the literature had not considered the long-term benefits of WMT, as there are studies that specifically assessed changes in WMT throughout different age groups (Loosli et al., 2011; Brehmer et al., 2012; Bastian et al., 2013; Heinzel et al., 2013), as well as studies that investigated effects of WMT following a stand-down period from the intervention (Dahlin et al., 2008; Jolles et al., 2010). Rather, this relates to the similarity in training principles between physiology and/or coaching pedagogy and WMT, a perspective that may not be typical of researchers in the field of neuropsychology (although Faubert and Sidebottom, 2012, did mention such a concept from a perceptual-cognitive training perspective). For example, it is suggested that a distributed training dose (> ~48 hours rest between training sessions) appears to be more effective than a concentrated dose (< ~48 hours rest between training sessions in creating trained and transfer gains) (Penner et al., 2012). In addition, the literature examined in Section 2.2 also suggests that distributed training has a greater association with gains in transfer task performance, which may indicate a more generalised performance effect. The benefit of a longer rest period is reflected in physiological training, where the progressive overload principle is applied (Faubert and Sidebottom, 2012) to manage overload, recovery and adaptation following a training stimulus. Put simply, cut the rest period short, and the full extent of adaptation following a training stimulus is difficult to achieve.

A second example of the impact of studying the literature from a coaches perspective was the similarity between the difficulty algorithm for WMT (Bastian et al., 2013; von Bastian and Oberauer, 2013) and the challenge vs success ratio mentioned in coaching literature (Light, 2004; 2013). Interestingly, this also relates to a key principle of Flow Theory – the balance of challenge and skill (Csikszentmihalyi, 1996; Dietrich, 2004), which suggests that the WMT difficulty algorithm may be representative of a global principle for learning and/or performance.

One of the challenges identified in this research was the need to address power relationships and resistance to new methods in Football Coaching. This was addressed by the use of a PAR methodology that empowered the coach to influence how new practice was used, however, the systemisation of the research literature through a coaching lens may have also been helpful in addressing this barrier, as it allowed the new methods to be presented in coaching language that was analogous to existing practice and concepts such as progressive overload (Faubert and Sidebottom, 2012), challenge vs success (Light, 2004, 2013), and Flow Theory (Csikszentmihalyi, 1996; Dietrich, 2004). Overall, the coach's perspective helped to understand how WMT could be systemised and applied, as opposed to trying to improve understanding of mechanisms and neurological effects.

The study of WMT was borne from the studies examined in Chapter 2, where perceptual-cognitive training and its effects had been investigated, but did not seem to be systemised (as highlighted by Faubert and Sidebottom, 2012), whilst the tasks used seemed to be more of a distraction designed to occupy working memory (Gabbett and Masters, 2011) rather than tasks that could affect the infrastructure underpinning perceptual-cognitive skill, and consequently, performance. The investigation of WMT addressed these two gaps in knowledge by, first, providing an evidence-based and systemised approach to affecting the neurological structures supporting working memory, and therefore perceptual-cognitive skill. This meant that it could be possible to periodise WMT in a similar manner to physical training, leading to the conceptualisation of WMT within a periodised Football Coaching model. Secondly, the dual task methods used in the literature had been used to investigate implicit motor learning (Gabbett and Masters, 2011). Implicit motor learning is beneficial to performance, as implicit skills have been shown to be faster and more stable under stress (Buszard and Masters, 2017), whilst the activation left for top-down adaptation from the cognitive system may allow better adaptation and/or mediation of responses in reference to the environment. The use of WMT as a dual task creates the possibility to concurrently develop the systems underlying perceptual-cognitive skill whilst encouraging implicit learning. The difficulty is still practicality, which was in part addressed by Study 1, but will still require future developments to form an effective method. At the least, it appears that the dual task methods previously used may be improved, with developments in technology providing a potential catalyst for use in Football Coaching practice.

Regarding practical application, this research did not only consider improvements in perceptual-cognitive training and the use of WMT, but also approached the integration of WMT into Football Coaching via a model that relates to the hierarchical layers of Football Coaching. This meant that it was important to understand more than how WMT could be used in a training session, but also how WMT could apply within the training week and the development of a

Playing Model, complementing the other components (such as physiology) that make up Football Coaching methodology. By considering the use of WMT within the whole structure of a Football Coaching model (in addition to the principles of WMT), this research was able to understand WMT in a language familiar to coaches. This helps to address the barriers associated with introducing new coaching practice, whilst also addressing the lack of conceptualisation and/or application of perceptual-cognitive training within a full coaching methodology.

It seems that this research was able to improve understanding of how WMT could be used in Football Coaching practice. However, a key step in integration is understanding how WMT impacts skill performance. Previous work had looked at assessing the impact of mental fatigue on skill performance (Smith et al., 2017), other studies have assessed skill performance in controlled tests (Ali et al., 2007; Ali et al., 2008; Ali, 2011; Serpiello et al., 2017) and there has been work assessing the impact of WMT on a dual motor-motor task (Kimura, Kaneko and Nagahat et al., 2017). Studies 2 and 3 of this research used WMT as a dual task on a test of football skill – the LSPT. Study 2 reflected the concern that the LSPT lacked validity compared to match performance (Serpiello et al., 2017), albeit based on the role of working memory in the test, not correspondence to match performance metrics. Along with changes in the prescription of WMT to an action-based metric with an arbitrary upper speed limit (there were previously no benchmarks for adjusting WMT difficulty when developing motor skills), this research adjusted the LSPT to incorporate working memory to a greater degree, theoretically increasing the performance validity of the LSPT. This was done by introducing the Stroop task into the LSPT, forcing participants to deal with both contextual interference and the inhibition of reflexive bottom-up responses during the test. Whilst this change does not mean that the test reflects the specific complexity associated with playing against an opponent under stress and/or fatigue, the test still engages the fundamental structures and processes required for skill performance in football, potentially moving the test closer to validity.

Finally, this research demonstrated, within a limited sample, that WMT dose as a dual task can influence skill performance, with meaningful effect sizes found in the second intervention study. The results in the experimental group indicated that working memory performance and motor skill performance could be developed concurrently, with further work needed in developing training methods and testing with larger samples for longer periods. These effects were demonstrated by the influence on skill accuracy, which also reflected previous work highlighting a speed-accuracy tradeoff in response to mental fatigue (Rozand et al., 2015; Smith et al., 2017).

To summarise, the literature framing this research demonstrated knowledge gaps in perceptual-cognitive training methodology in sport (and football), the systemisation of WMT and the understanding of how WMT as a dual task could impact performance. This research addressed these knowledge gaps sequentially through Chapters 2-7 by investigating the mechanisms of perceptual-cognitive training, before conceptualising, systemising and applying WMT by investigating its use in practice and its impact on skill performance. The evidence in this research is early stage research, and as such does carry some limitations. The limitations are discussed in the following section.

8.4 Research Limitations

This research theorised and investigated a new training method for Football Coaching. By nature, the investigation process was early-stage and exploratory, so evidence in this research needs to be considered within the context of its limitations.

Firstly, the exploratory nature of the research process limited the context within which the investigation could take place, which also impacts the generalisability of the evidence. The research was completed with non-professional participants with a sample size and intervention period that was limited by the availability of participants. However, this allowed the investigation to be carried out with a low risk of negative bias towards new methods from participants, so in some part this may have been an advantage to carry out these early studies, especially considering the intimate nature of the qualitative research process in Study 1. The benefits experienced in Study 1 are counterbalanced by the limitations in Study 2 where there was an impact on the random selection of participants, as some participants would normally have been screened and rejected following the pre-test, the study couldn’t reject participants without compromising the sample size. An answer to the contextual limitations could have been to run these investigations across multiple contexts, but the resources available (time, funding, equipment, staff) wouldn’t have allowed this possibility.

A second limitation was the lack of available technology required to investigate all the issues highlighted fully. Whilst future work can be framed on this issue, it would have been advantageous to the investigation to be able to test WMT in Football Coaching practice using sub-vocalisation and bone-conduction technologies to collect non-verbal responses, or have investigated the impact of WMT on an LSPT-Stroop where the Stroop location and selection criteria could be randomised for each action. Having this technology available may have allowed the research to perform a more extensive investigation, however, the benefits of these technologies may not have been identified without this investigation taking place in the nature it has.

In comparison to the research literature, there are a small number of criticisms that could be made of this research. First, it has been highlighted that there is a lack of understanding regarding the specific mechanism of working memory that deals with motor input (Buszard and Masters, 2017), and this research did not seek to address that issue. This was due to both the practice-oriented intention of the research and the suggestion that research focusing on dynamic skills and everyday tasks related to executive function may be a beneficial approach for the time being (Buszard and Masters, 2017). Therefore, exploring the mechanism by which working memory handles motor input was outside of the scope of this research, best left to future experimental work by researchers with expertise in that area, although the research here may indirectly contribute to future work in that paradigm.

The qualitative element of this research did use WMT as a dual task with a verbal task delivery and response in its design, which could be considered impractical, per previous work (Gabbett and Masters, 2011). However, this research investigated the issues underlying the impracticality of dual tasking in coaching by addressing pedagogical issues whilst looking at how technology could develop practicality. The impracticality of dual tasking became a tool that allowed the investigation to take the direction carried out in Study 1.

Implicit skills are considered to be a faster and more stable alternative to explicit skills under conditions of stress, fatigue and pressure (Masters, 1992; Masters et al. 2008), and therefore are an important mechanism underlying perceptual-cognitive skill. It could be argued that focusing on methods encouraging implicit learning and keeping cognitive resources free for adaptation of skills would have a similar benefit to the methods investigated in this research. An important distinction in addressing that criticism is that whilst WMT as a dual task encourages implicit learning in a manner typical of dual task training, by occupying working memory (Furley and Memmert, 2010; Furley and Wood, 2016; Buszard and Masters, 2017), it is also suggested to impact the plasticity (Dahlin et al., 2008; Loosli et al., 2011; Takeuchi et al., 2011; Bastian et al., 2013) and process efficiency (Dux et al., 2009; Jolles et al., 2013) underlying the ability of working memory to manipulate and adapt responses for context. Therefore, by using WMT, it may be possible to develop greater available capacity and ability to adapt responses to novel situations, as well as fundamentally developing fast and stable responses. An example highlighted in this research is the idea of developing an implicit Playing Model that can be adapted quickly to match situations, based on constraints presented by the opponent, score, result consequences and/or time remaining.

Increasing available working memory capacity during performance may have its drawbacks, as there is no guarantee that the activation would be used for task-relevant actions. Responses such as a drift in attention (Dietrich, 2003) or a previously unobserved stress response could be handled by the activation, either of which could be associated with skill breakdown or a Choking response (Yu, 2015). On that basis, creating more available activation could be potentially detrimental to performance. A solution is to ensure that the increased activation is directed to task-relevant actions through psychological skill training methods (Bijleveld, 2014), which can also be supported by the clarity of the task at hand (aided by task clarity and cues in the Football Coaching process – per Cross et al., 2013). Assuming that available activation is used for task relevant actions, it seems that increasing the available activation to manipulate and adapt implicit responses would improve performance by developing athletes that can adapt responses faster than the opponent, whilst performing actions that are faster and more stable.

Finally, it could be argued that the LSPT has been validated in the literature with a greater weight of evidence than this research, which criticises its validity. The validity of the LSPT is questioned in this research with regards to the decision-making element that is intended to be part of the test (Ali et al., 2007), whilst other purposes, such as avoiding the subjectivity of assessing skill during match play or testing skill without a physiological demand (Ali, 2011) are not questioned and still seem to be valid. The evidence presented in this research has limitations in sample size and dose, which could mean that questioning the LSPT validity could seem too strong. However, the decision-making element of the LSPT can be questioned in both a theoretical manner and an evidence-based manner, as it does not incorporate contextual interference or a suppression of previous habit (Furley and Wood, 2016), and changes in WMT difficulty were dramatically different between Chapters 6 (where the normal LSPT was used) and 7 (where the Stroop task was incorporated). The LSPT has also been questioned with regards to match validity (Serpiello et al., 2017). Therefore, whilst the evidence presented in this research may not be the most extensive, when considered in the context of decision-making theory and other research using the LSPT, the addition of the Stroop task may be beneficial to LSPT use.

In summary, this research is in an early stage form and does carry some limitations. In some cases, the limitations aided the novelty of the investigation, but were often counterbalanced by negative effects. Based on the literature there are some valid criticisms of the research, but these criticisms are largely addressed within the investigation here or in specific literature. In many cases, the potential criticisms relate to some findings of the research, reinforcing the position of the evidence discussed. Due to the limitations and potential criticisms, there is a scope for future work following this research, discussed in the following section.

8.5 Future Work

This research has been able to relate to previous literature and address some gaps in knowledge, albeit with some limitations and need for future work. The following are three directions for future work relating to the investigation presented in this research:

- Research and development of technology alongside appropriate pedagogy to make WMT feasible in coaching practice
- Investigation of the impact of a full application of WMT within a team environment over the course of a competitive season(s)
- Larger sample studies with a developed LSPT-Stroop investigating the impact of WMT on skill performance

These three objectives are a continuation of the research questions investigated in this research. Following the qualitative data analysis in Chapter 2, it is apparent that a system could be built to support the use of WMT during football training sessions. The system should incorporate automatised and individualised task delivery, the ability for coaches to remotely control WMT, and the use of bone conduction (May and Walker, 2017) and sub-vocalisation technology (Kapur et al., 2018) to allow participants to receive and send a non-verbal, non-motor response. Building and investigating the use of such a system is a key objective following this research and would allow further investigation of the application of WMT to take place.

If a WMT delivery system can be built for coaching practice, then another objective for future work would be to assess the impact of using WMT within a team environment, using the conceptualisation in Chapter 3 as a framework through which to use WMT. Any investigation with this aim in mind would need to consider the pedagogical implications as well as measuring performance benefits. It would be recommended that such an investigation would be of a mixed methods variety, working collaboratively with the coaches and athletes to improve application before leading into quantitative work to establish the impact on performance. Depending on the results of such work, it may be possible to use WMT as a tool for talent identification or assessment of learning. It would also be interesting to understand the possibilities of developing an implicit Playing Model within a team.

Finally, it seems necessary to carry out further work assessing the impact of WMT on skill performance, whilst also improving the validity of skill assessment tests in football. Creating an LSPT-Stroop where the target location and selection criteria are randomised for each action would help the investigation of using WMT to affect skill performance, which could also be developed using larger sample sizes, more competent populations and longer period interventions. Further developments in that research may also help contribute to the understanding of how working memory deals with motor input.

Future work in each of these areas would contribute to the understanding of the acquisition and mechanisms of perceptual-cognitive skill. As part of a wider trend in research, future work may contribute to a wider use of perceptual-cognitive training methods in football, introducing a new training paradigm. There is plenty to be done before strongly making any of these claims.

8.5.1 Practical implications

Despite the studies conducted demonstrating that there may be some merit in developing the use of WMT in football coaching for the purpose of performance, the practical implications to coaches remain limited until technological and methodological issues highlighted by this research are better understood. Immediate practical implications from this research regard the use of problem-solving pedagogy when using dual tasks and the improved relevance of the LSPT to performance when used with a STROOP test, due to the replication of working memory use. It is possible that the LSPT-STROOP used with WMT may be a superior talent identification tool compared to the original LSPT, but that would need its own specific investigation. This research demonstrates that the future of best practice in football coaching may include some form of training designed specifically to develop the neurological structures underpinning expert performance, but that possibility needs substantial further research and development.

In contrast, the literature reviews included in this research provide a synthesis of how skilled performance is executed and can be developed. Chapters 2 and 3 provide insight into how coaches can structure and influence the experiential environment of athletes to develop perceptual-cognitive expertise in their domain, taking into account perception, decision making, motor learning and underlying psychological considerations such as inducing Flow and decreasing Choking susceptibility. Pedagogical implications include the use of implicit motor learning strategies wherever possible, and the importance of creating clear and simple explicit references when creating behaviour models in sport - allowing the fast retrieval and adaptation of implicit responses during performance. Finally, the presentation of WMT principles in Chapter 2 may positively influence the investigation of WMT in the future, providing a consistency in prescription which could make studies easier to compare – though this is a practical implication that is possibly better suited for the field of neuropsychology, not sports necessarily sports coaching.

8.6 Conclusion

This research demonstrated a journey from the conceptualisation of how new perceptual-cognitive training methods could be applied to develop the structures underpinning Perception, Decision Making and Execution in football, to the investigation of how WMT could be applied in practice and affect skill performance. The investigation was able to take existing knowledge from the literature and address several gaps in knowledge regarding the systemisation and application of new perceptual-cognitive training methods in Football Coaching, addressing both pedagogical and methodological issues. This research was challenging in some of the limitations created by the research context, but ultimately, the limitations and criticisms that could be made of the research have helped to fuel the findings and direction for future work. To continue this work, new systems need to be built and tested in real world practice, which may aid our understanding of the nature of expert performance in sport and the “hardware” underpinning perceptual-cognitive skill. If future work can be applied, it is possible that this area of research could advance coaching practice, improve athletes, and therefore improve football itself.

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Appendices

Ethical Approval

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

HUMAN ETHICS COMMITTEE

Secretary, Lynda Griffioen
Email: human-ethics@canterbury.ac.nz

Ref: HEC 2013/30/LR-PS

6 September 2013

Joseph Hall
School of Sport & Physical Education
UNIVERSITY OF CANTERBURY

Dear Joseph

Thank you for forwarding to the Human Ethics Committee a copy of the low risk application you have recently made for your research proposal "Integration of working memory training into contemporary best practice of football coaching".

I am pleased to advise that this application has been reviewed and I confirm support of the Department's approval for this project.

Please note that this approval is subject to the incorporation of the amendments you have provided in your email of 4 September 2013.

With best wishes for your project.

Yours sincerely

Lindsey MacDonald
Chair, Human Ethics Committee

Consent Form Study 1

School of Sport and Physical Education

Telephone: +64 27 356 65 62

Email: joseph.hall@pg.canterbury.ac.nz

Consent Form for participants

☐ I understand the requirements of this project and have had an adequate opportunity to ask questions.

☐ I understand that participation requires involvement in a minimum of three training sessions spread across a 5 week training programme. I also understand that I may be required for an informal interview and that transcripts of any interviews will be made available on request.

☐ I understand that participation is voluntary and I may withdraw at any time without penalty.

☐ Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.

☐ I understand that any information or opinions I provide will be kept confidential to the researcher and research supervisors Assoc. Prof Jeanne Kentel and Dr Zhe Chen

☐ I understand that a thesis is a public document and will be available through the UC Library.

☐ I understand that all data collected for the study will be kept in locked and secure facilities and in password protected electronic form and will be destroyed after ten years. I understand that my activities will be captured on video.

☐ I understand that this project presents equal risk to football participation and that appropriate first aid and warm up/cool down strategies will be used the minimise injury risk.

☐ I understand that I am able to receive a report on the findings of the study by contacting the researcher at the conclusion of the project.

☐ I understand that I may be recognized on video clips that will be part of the publicly available thesis even though my real name will not be used in the research.

☐ I understand that I can contact the researcher Joseph Hall (joseph.hall@canterbury.ac.nz) or supervisor Jeanne Kentel (jeanne.kentel@canterbury.ac.nz) if I have any concerns or issues

☐ If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (humanethics@canterbury.ac.nz)

By signing below, I agree to participate in this research project.

Name: Date: Signature:

Please return via email to joseph.hall@pg.canterbury.ac.nz by September 28th, 2015

Joseph Hall

Consent Form - Study 2

School of Sport and Physical Education

Telephone: +64 27 356 65 62

Email: joseph.hall@pg.canterbury.ac.nz

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Consent Form for participants

☐ I understand the requirements of this project and have had an adequate opportunity to ask questions.

☐ I understand that participation involves working memory training during a football skill testing protocol

☐ I understand that participation is voluntary, and I may withdraw at any time without penalty.

☐ Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.

☐ I understand that a thesis is a public document and will be available through the UC Library.

☐ I understand that all data collected for the study will be kept in locked and secure facilities and in password protected electronic form and will be destroyed after ten years.

☐ I understand that this project presents equal risk to football participation and that appropriate first aid and warm up/cool down strategies will be used the minimise injury risk.

☐ I understand that I can contact the researcher Joseph Hall (joseph.hall@canterbury.ac.nz) or supervisor Nick Draper (nick.draper@canterbury.ac.nz) if I have any concerns or issues

If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (humanethics@canterbury.ac.nz)

By signing below, I agree to participate in this research project.

Name: Date: Signature:

Please return in person or via email to joseph.hall@pg.canterbury.ac.nz

Joseph Hall

Consent Form Study - 3

School of Sport and Physical Education

Telephone: +64 27 356 65 62

Email: joseph.hall@pg.canterbury.ac.nz

UNIVERSITY OF CANTERBURY
Te Whare Wānanga o Waitaha
CHRISTCHURCH NEW ZEALAND

Consent Form for participants

- ☐ I understand the requirements of this project and have had an adequate opportunity to ask questions.
- ☐ I understand that participation involves working memory training (WMT) during a football skill testing protocol
- ☐ I understand that participation is voluntary and I may withdraw at any time without penalty.
- ☐ Withdrawal of participation will also include the withdrawal of any information I have provided should this remain practically achievable.
- ☐ I understand that a thesis is a public document and will be available through the UC Library.
- ☐ I understand that all data collected for the study will be kept in locked and secure facilities and in password protected electronic form and will be destroyed after ten years.
- ☐ I understand that this project presents equal risk to football participation and that appropriate first aid and warm up/cool down strategies will be used the minimise injury risk.
- ☐ I understand that I can contact the researcher Joseph Hall (joseph.hall@canterbury.ac.nz) or supervisor Nick Draper (nick.draper@canterbury.ac.nz) if I have any concerns or issue

☐ If I have any complaints, I can contact the Chair of the University of Canterbury Human Ethics Committee, Private Bag 4800, Christchurch (humanethics@canterbury.ac.nz)

By signing below, I agree to participate in this research project.

Name: Date: Signature:

Co-signed by parent/guardian:

Name: Date: Signature:

Please return in person or via email to joseph.hall@pg.canterbury.ac.nz

Joseph Hall